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This is a monthly publication presenting brief articles concerning recent developments in European Scientific Research. It is hoped that these articles (which do not constitute part of the scientific literature) may prove of value to American scientists by disclosing interesting information well in advance of the usual scientific publications.

The articles are written primarily by members of the staff of ONRL and occasionally articles are prepared by, or in cooperation with, members of the over

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Aubrey W. Pryce and Victoria S. Hewitson

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ENERGY

SWEDEN HAS A BETTER IDEA—DISTRICT HEATING

"District Heating" is the name given, in Sweden, to a large central heat-producing plant that supplies heat for a nearby district including homes, apartments, office buildings, and industries. I am told that more than half of the country's buildings are now being heated this way.

To see how this system is working in practice, I made a trip to Enköping which is an hour by train to the north and west of Stockholm. This small city of 20,000 people decided to introduce district heating in 1969, and a private company (AB Enköping Värmeverk) was formed to develop it. Subscription to the system is entirely voluntary; 80% of the technically feasible heat load in Enköping has been connected including about 500 single family homes. The original design was built around an oil-fired hot water system with about 40 km of well-insulated distribution pipes laid in underground culverts.

In the 1973 oil crisis, oil supplies were cut off long enough to underline the importance of developing a facility that could use a variety of fuels to ensure continuity of heat during any future restrictions on fuel. This, of course, is a problem not only for Enköping but for all of Sweden. In April 1975, the Swedish National Environment Protection Board announced its approval of the development of a hot-water and a combined heat and power station using multi-fuel firing in a fluidized-bed facility at Enköping. The government granted a 50% subsidy to the capital cost of the 25-MW demonstration and pilot plant that is also supported by the Swedish District Heating Association.

An earlier *ESN* (32:1-4) mentioned that the initial firing of this multi-fuel system was imminent; my trip to Enköping was motivated in part to see how it was working. Mr. D.A.A. Arthursson was my host. He is a consulting engineer for AB Enköpings Värmeverk and has managed the design, installation, and testing of this new system. Over the period from 1978 to 1980 there will be a trial and demonstration period using various fuels. The attempt will be to show operation with high sulfur oil, powdered coal, milled peat, and wood chips. These last two fuels could be produced locally in Sweden. Arthursson feels that, if the tests are successful, the development of this heat source will be the biggest advance in district heating since its inception. He expects that more than 50 multi-fuel fluidized-bed combustion hot-water boilers will come into operation in Swedish district heating plants during the next 10 years.

The fluidized-bed generator has a diameter of about 3.5 m and a total height of 9 m. When used with solids, there is enough vertical flow of gas (2.5 m/sec) to keep the fuel stirred and burning throughout the generator volume. In the slumped (non-fluidized) state, the depth of the bed is 0.25 m. Initial one-day tests were made with each of the four fuels to show that operation was possible. The program then concentrated on optimizing the use of high sulfur oil as a fuel.

High sulfur residual oil is left over from vacuum distillation of oil and may contain as much as 3.6% of sulfur. The low sulfur oils generally used in heating have less than 1% of sulfur, and environmental protection codes are designed for them. High sulfur oils are only 1/3 the cost of low sulfur oils but can only be used at present as fuels in ocean-going vessels where environmental protection regulations have not yet penetrated. In the fluidized bed the trick is to mix into the bed an appropriate amount of the mineral dolomite crushed to 0.5-3.0 mm size. At the temperature of the bed (850°C) the dolomite reacts with the sulfur to form a Ca/S ratio of 1:5, and 75% of the sulfur is removed thus coming well within Sweden's emission specifications. The spent dolomite is removed as a waste product.

Other pollution problems also seem to be under control. Monitoring for nitrous oxides and heavy metals shows them to be quite low. Before entering the stacks, all the gas is passed through very heavy particle filtering to remove ash and smoke down to micron sizes. It is claimed that no smoke has ever been seen coming from the plant.

At this point the development program for high sulfur oil is complete. Optimum procedures for start up, running the fluidized bed, shut down, and emergency control are encoded in a microprocessor that controls the system. Its operation is entirely automatic at night and on weekends. The only emergency so far was induced when one of the

operators turned off the wrong valve by mistake. The computer moved efficiently to shut the plant down. Once they have been developed, programs for the other fuels will also be encoded into the microprocessor so that changing from one fuel to another can be done with ease.

Plans are to work with coal, next, which is anticipated as the normal fuel for this system with oil used only as a standby. A two-year supply of coal is stored nearby. The plan is that the fluidized bed will be the heat source in constant operation with the two oil-fired systems being used at peak demand periods and in emergencies.

The ability of the fluidized-bed generator to use low cost fuels such as coal and high sulfur oil compensates for the 30% greater capital cost of this type of burner. In addition, of course, the larger use of coal helps to diversify the fuel supplies. Sweden gets only 4% of its energy from coal at present; oil supplies a whopping 72%.

The district heating plant at Enköping is measured to be about 92.5% efficient with less than 2% additional loss in the distribution system. This contrasts favorably with boilers in individual homes which are only about 75% efficient even when perfectly adjusted and cleaned; more normally, values in the range from 60% to 65% are measured. District heating is obviously a more efficient way to supply heat.

Another advantage of district heating is that it is easy to add other sources of waste heat into the system. At Enköping a small amount of heat comes from burning the methane produced when solid wastes are digested in the sewage plant. Local industry that has excess heat—such as the paper industry—can find a market for it in a district heating system. A very important source of waste heat is from electrical generating stations. These typically operate at only 35% to 40% efficiency with the remainder lost as heat. To make it more graphic, for every three barrels of oil burned in an electrical generating plant, the equivalent of only about one barrel goes out of the plant as electrical energy. The rest is heat. It has been obvious to the authorities in Sweden that coupling an electrical power generating plant to a district heating system would be a good way to use this waste heat. As mentioned earlier such a combination is planned for Enköping. I was told that all of the electricity generating plants constructed in Sweden in the last few years have been designed to be joined to district heating systems. The only exception is a standby system for a nuclear powered generator. An electricity generating station has to be sized to correspond to the district heating system to which it is connected, and this leads to a larger number of smaller electricity generators. Their inherent efficiency may be slightly less, but distribution losses will be small because they can be close to the area they serve. The big advantage, of course, is that their waste heat can be utilized. As an example, take a very large electricity plant operating at 40% efficiency and compare it with a smaller plant operating at 35% efficiency for electrical conversion. Even if only half of the heat from the smaller plant can be used in a district heating system, its overall energy efficiency is then raised to 67.5%. The existence of district heating systems thus allows an enormous increase in the efficiency with which fuel is used.

Finally, the advent of district heating localizes the burning of fuel in a few places in the district. With efficient combustion and rigid filtering, smoke and noxious emissions can be substantially reduced. Arthursson claims that the neighboring industrial city of Västeras changed dramatically from having a dirty and polluted atmosphere to that of a lake resort town when district heating took over.

It is not often a development appears that not only reduces the need for fuel but improves the environment at the same time. Sweden indeed has a better idea. (Clifford C. Klick)

ONRL REPORTS

See the back of this issue for abstracts of current reports.

SOLAR ENERGY STUDIES AT THE UNIVERSITY COLLEGE, CARDIFF

The Department of Mechanical Engineering and Energy Studies at the University College of Cardiff, under the direction of Prof. E. Markland, has a faculty of two professors, one senior lecturer, seven lecturers, five research fellows, and seven research assistants. The Department is well equipped for research in fluid mechanics, materials, vibrations, noise, automatic control, fluidics, engines, heat and mass transfer, and combustion. However, the outstanding feature is its Solar Energy Unit, directed by Prof. D.J. Brinkworth, which is the only university group in Britain concerned with the engineering of solar energy systems.

Activity in solar energy was initiated at Cardiff in 1964 by Brinkworth, who was then a Reader. His original interest was in thermal radiation transport in the atmosphere and the scattering of light on paint films and other particulate suspensions. In subsequent years, a general reappraisal of energy sources and growing support for work resulted in contract activity funded by industry, the Science Research Council, the Departments of Energy, of Industry and of the Environment, and the European Economic Council. At present, the full-time personnel of the Unit numbers 22.

Although the Unit is interested in generalized solar energy, the current work is concerned only with those applications that are closest to economic viability. Hence, there is a program on the study of the absorption and emission characteristics of solar collector surfaces and the development of low-cost radiatively selective surface coatings. Another investigation involves the hydraulic design of collector passages and the mechanism of the corrosion failure of collectors. Various aspects of thermal energy storage are also under investigation, and a computer data bank on materials that store energy by undergoing a physical phase change has been built. Because conditions for satisfactory operation in Britain and northern Europe are marginal, it is particularly essential that solar collector systems be optimized.

The Unit has been designated as the United Kingdom's participating body in the solar heating and cooling program of the International Energy Agency and takes part in the testing program of that Agency. Because repeatable test conditions are difficult in the British climate, the Unit has developed a solar simulator which is now in regular operation, and which provides continuous radiation energy flux of up to 800 w/m^2 over a 2-m-diam. test area. The simulator provides any required orientation of the source and of the irradiated device, and accordingly it is possible to simulate radiation for any place on earth at any time or season. The radiation source of the solar simulator consists of a number of units of a 1-kW sealed-beam compact source metal halide lamp and matches the solar spectrum fairly well.

An investigation concerning the storage of energy in a change of phase from solid to liquid is under the direction of an American, Dr. Richard H. Marshall, who studied at the University of Michigan. The materials being investigated are the family of paraffin waxes; although salt hydrates (calcium chloride hexahydrate) are more efficient than paraffin waxes, they are more difficult to handle. During the 1940s, I recall that Dr. Maria Telkes was investigating the use of salt hydrates for energy storage at MIT. The latent heat of fusion of industrial paraffin is 210 J/g and represents a 60°C interval temperature rise in water. The difficulty that arises in the use of a solid-to-liquid phase change as a means for storing heat lies in the heat exchanger required to add heat to, and to extract heat from, the material. Marshall is conducting studies of the geometry for most efficient storage and is combining experiment with computer modeling. The advantages of a two-phase heat storage system are that it beats the volume of water for storing a similar amount of heat by a factor of 3 for a normal temperature operating range, and that the collector operates at essentially one temperature. However, the cost of such storage is higher than for a pure liquid phase storage.

An investigation of solar pond heat storage is under the direction of Mr. M.N.A. Hawlader, who has a column of saline solution of stratified density with a black heat absorbent bottom. The column is about a meter high and 25 cm in diameter and has a single lamp providing radiation. The black bottom of the column absorbs heat, and the stratification of the saline, which varies

from pure water at the top to 20% salt content at the bottom, keeps the heat trapped at the bottom. If, however, heat is added too rapidly, the expansion of the solution at the bottom opposes the saline stratification tending to stabilize the column and a convective instability develops. This convective instability might then develop progressively along the column from the layer at the bottom. The difficulty with the experiment is that the apparatus hardly simulates the solar pond because many modes of convective instability are stabilized by the presence of the walls. In addition, to make the system work, the salinity gradient must be maintained, and this might prove impossible in the face of ordinary diffusion effects along with the turbulent diffusion caused by a convective instability.

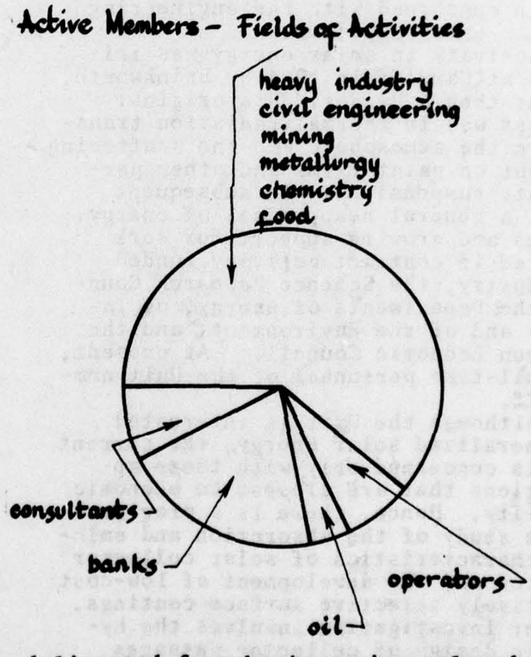
Since much of the work going on in the Unit is supported by industry and is of a proprietary nature, it is difficult to find out precisely the stage of development of the various components under study. However, I was impressed with the quality of the work and feel that the Unit is contributing meaningfully toward attempts to resolve our energy difficulties. (Martin Lessen)

SEA POWER—ALTERNATIVE MARITIME ENERGY SOURCES

The Society for Underwater Technology in London recently held a seminar on "Harnessing the Sea's Physical Energy Resources." This article will highlight the major points of this extremely informative meeting.

The latest production estimates by Great Britain's Watt Committee on Energy put the North Sea oil turnover point as somewhere in the 1983-1985 time frame (i.e., after probably peaking during 1984, production will fall fairly rapidly), most likely causing the UK to become a net importer shortly thereafter. The natural gas situation is better, especially since viable Synthetic Natural Gas (SNG) production methodology appears to be just around the corner. Coal deposits should provide extractable yields for up to almost three centuries, and nuclear fission could be meeting a substantial part of the world's energy requirements by the year 2000. Nuclear fusion is still in the Buck Rogers stage, few scientists speculating practicality any earlier than the year 2050.

But, what about the so-called Alternative Sources (as defined by European countries)? First of all, they break this category down into the more manageable subsets of (1) solar, (2) waves, (3) winds, (4) tidal, and (5) geothermal. *EUROCEAN* is a consortium of 25 industrial companies from the nine European countries of Belgium, France, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the UK. Member companies include the European Credit Banks and the French Petroleum Company, Fiat, the Midland Bank Group, and Nestlé; with the National Swedish Board for Technical Development as an associate member (see figure). This esteemed organization has



delineated four basic marine-related resources to be explored for possible future developmental work: energy, living resources, raw materials, and chemicals. Understandably, the conference dealt with the energy projects: (1) Ocean thermal energy conversion (OTEC)(see *ESN* 32-4: 128), (2) winds, (3) waves, (4) tides, (5) currents, (6) salinity gradients, (7) bioconversion, and (8) solar ponds. Note that depending on which organization enumerates alternative/marine energy sources, one can rapidly become confused in technological rhetoric. Suffice it to say that this article will merely apprise the reader of the present state-of-the-art in accordance with European scientific thinking.

OTEC. EUROCEAN, based primarily on techno-economic reasons, has placed top priority on OTEC, in which ten member companies are participating in the project now underway. Plans for the applied development and required engineering work have been set forth, and some component fabrication is underway. A 10-MW pilot plant should be ready for operation by 1981 (by comparison, America's OTEC-1, a 1-MW engineering component test facility should be operational by 1980). OTEC utilizes the temperature differential between warm surface waters and colder 1000-2000-m deep waters (up to 25°C gradient). By using, say ammonia, as a working medium that would boil at the upper temperature range and condense at the lower end, turbine power could be produced 24 hours a day, regardless of sun cycles or meteorological/oceanographic conditions. Huge seagoing plants are envisioned, producing upwards of 400 MW each.

The two main drawbacks of OTEC are the fact that plants will be restricted to the general area between 20°N and 20°S latitude, and that some futuristic technological breakthroughs are needed to make production of some of the components feasible. Of the six basic OTEC subsystems, the heat exchanger (which will ultimately absorb 40-50% of the total cost) needs the most development. The cold water pipe presents unique problems also; measuring approximately 1000-m long, 30-m wide, and most likely will be made out of concrete in 50-m lengths with flexible joints. Also requiring some innovative design development is the main structure itself (including housed pumps, electrical systems, filters, etc.), which will end up consuming 20-30% of the total cost. Again, concrete will probably win out over steel, fiberglass-reinforced plastic, and aluminum as the structural element. The turbine systems and transmission cables (probably dc) should pose no insurmountable problems, and the necessary mooring system technology is available thanks to the burgeoning offshore oil industry. Other pertinent facts are that each plant will probably weigh upwards of 5 Mtons, generating energy at about 30% efficiency, it is to be hoped for a 30-year lifespan. Major companies currently involved in OTEC are those within EUROCEAN and US- and Japan-based multinational organizations.

WINDS. EUROCEAN's next choice is large offshore wind-energy systems. Advantages over their land-based counterparts are: (1) greater available area, (2) higher mean wind velocity, and (3) decreased environmental problems of safety, noise, interference, and aesthetics. The best computer estimates reveal that the higher costs of offshore installation (about six times greater than a comparable onshore system, but up to twelve times greater in an environment as harsh as the North Sea) should be offset by the marked increase in energy production from the higher mean wind velocities. EUROCEAN's Wind Energy Group is in the conceptual phase, currently studying siting problems, collected data, system identification, connection to present European power grids, and definition of national policies and markets.

Theoretically, windmills can be 50% efficient, and British experts believe they could ultimately supply at least 25% of the UK's electricity needs. In fact, given a coordinated program, spending about $20 million over the next 5 years, large offshore windmills could be deployed in the early 1980s, harnessing a significant portion of the wind energy resource by 1990.

Given the average 9 m/sec wind speeds off the Norwegian coast, 180 windmills, each weighing approximately 10 ktons, standing 136-m high with 100 m of cross-sectional blade area, could generate 900 MW. The windmills would be situated in 18 clusters of 10 platforms each, along a 45-mile stretch of coastal water, not exceeding 10-m depth.

WAVES. Mid-Atlantic power densities of 80 kW/m of wave frontage have been measured, but a floating structure of at least 15-m draft and comparable width would be required to extract this energy potential. Recently-collected data off the Scottish coast indicate feasible energy reception schemes should be able to harness about 40-50 kW/m.

The UK's Wave Energy Programme has declared that mean annual power output from this resource could be as high as 8-9 GW. System studies have been carried out on Salter's "Ducks," Cockerell's Wave Contouring Rafts, Oscillating Water Columns, the Russell Rectifier, and the Vickers Wave Energy Converter (See *ESN* 32-4:124). The theoretical background of wave energy conversion rests on the fact that any oscillating structure moving in a single mode of motion can be an

effective wave energy absorber if it can efficiently generate unidirectional waves when driven in reverse. Based on this common scientific reality, many of the devices under consideration have similar characteristics.

The main problem areas in exploitation of wave power are: (1) wave direction variability, (2) power transmission lines, (3) structural moorings, (4) structural size, (5) structural strength, (6) corrosion, and (7) marine growth. Once again, concrete will probably be the material of which any future wave energy devices are built.

Salter's "Ducks" (See *ESN* 32-4:128) have been the most widely publicized contrivance, and studies have revealed that theoretically 90% power extraction is possible. However, realistic problems such as unacceptable torque stresses on the spine, power variability, and the inherent interdependence of all elements (45% of power output could be lost if only a few components failed), will most likely render this type of device infeasible for further future development. Cockerell's invention, a series of hinged pontoons that float up and down on the waves deserves mention; tests financed by UK's Department of Energy were carried out during the latter part of 1978 and results are still being analyzed. The most promising new idea is the Oscillating Water Column—promising because there are fewer potential mechanical problems; air turbines are run on the basis of a pressure differential. Even so, there are technological hurdles down the road, but these appear to be solvable, at least at this stage of development. The Russell Rectifier and Vickers Wave Energy Converter were not covered during discussions at this conference. The bottom line, with respect to the major difficulties inherent in extracting wave energy from the ocean, can be summed up as follows: "The device must be able to convert energy from 3-m waves with maximum efficiency, at the same time being able to withstand the onslaught of 30-m waves."

TIDES. UK Engineering and Power Development representatives reviewed tidal energy extraction schemes from river barrages. The only viable operational setup today exists in Rance, France (*ESN* 32-4:128). The plant was built twelve years ago, principally for demonstrative purposes (240-MW power output). Recent studies show that the Bay of Fundy in Canada (world's greatest tidal ranges) could deliver up to 4 GW and for "only" $3 billion could be operational by 1990. The USSR has had a small station in the White Sea for six years, of unknown potential.

The UK's only credible tidal energy prospects lie in the Severn Estuary (*ESN* 32-8:257). Contingency plans have been developed for a barrage across this river, but the opponents profess that such a project would change siltation patterns, altering physical contours and probably disrupting marine biological activities. Also to be considered would be the required modifications to previously established ship movement patterns in the area. The majority of UK energy experts generally regard this is a fallback alternative; to be seriously considered only if OTEC, wind, and wave energy extraction techniques prove infeasible or insufficient.

CURRENTS. Mentionable only because, based on today's technology, sustained velocities of 3-5 kts would be required to warrant feasibility studies. Accessible currents of this potential are not found in the vicinity of the UK or other European nations. Even the US has put off research in this field because the Florida Current is the only conceivable candidate and problems highlighted in a 1974 Miami-based technical meeting were of such magnitude as to make production costs prohibitively large today.

Salinity gradients, bioconversion (ocean biomass utilization), and solar pond systems have been studied by the European scientific communities in varying depth, but as yet pose no real competition to the likes of OTEC, where most of the money for research, development, testing and evaluation seems to be going.

Perhaps we should alter our way of thinking and heed the advice of one learned speaker who claimed that no matter how much money is spent on generating power from the sea, the greatest contribution to the energy gap in years to come could—and should—come from more rational use of energy, often referred to as that old nemesis: "energy conservation." Alas, only time will tell. (LCDR C.H. Spikes)

ENGINEERING

MISFETs AND MOSFETs IN THE MIDI

Midi in France and *mezzogiorno* in Italy mean not only midday, they also mean "land of the midday sun," i.e., southern France and southern Italy. It was Montpellier, in Languedoc, in the sunny Midi, that was the site of ESSDERC 78, the 8th European Solid State Device Research Conference. Held in collaboration with SSSDT, the 3rd Symposium on Solid State Device Technology, the meetings took place on the campus of the Université des Sciences et Techniques du Languedoc, on 11-15 September 1978. Since the campus of this University is less than twenty years old, one would think that it is a newly-established educational institution. Actually, the University boasts of a medical school that is one of the oldest in Europe, dating back to the 1500s.

MISFETs and MOSFETs—what are they? As readers conversant in the subject of semiconductor devices will know, these terms are acronyms used to describe the structure of two different types of transistors. The purpose of the ESSDERC and SSSDT was to advance the state of the art and knowledge in these and other electronic devices.

Conference Chairman was Dr. J. Borel, of the semiconductor laboratory of the atomic energy establishment LETI/MEA, Grenoble, France. Vice-Chairman and Secretary and responsible for the excellent local arrangements were Profs. M. Savelli and J.P. Nougier, respectively, of the host university. Prof. Peter Balk, (Institut für Halbleitertechnik, Aachen, FRG,) was Chairman of SSSDT. About 400 scientists and engineers from more than 25 countries participated.

Although the title implies that solid state devices of all types were discussed, this Conference dealt virtually only with semiconductor devices.

Borel's opening remarks stressed the continuing need for the device engineer to understand device physics. As he said, "Physics, with a special emphasis on the way it can help us overcome possible defects and how it relates to device performance is the major area of concern at this year's conference."

He then outlined some of the areas that he feels require attention. Efforts to produce devices of smaller and smaller geometry, for example, should deal with doping inhomogeneities, defects, thin epitaxial layers, and gettering. Studies on doping should treat basic diffusion mechanisms, ion implantation, and shallow junctions. Oxidation work should aim at thin layers with good yield and stability, a physical understanding of thin layer growth, and new techniques of passivating. Fabrication of devices of the future will require an understanding of dimensional control, parameter control, and reliability related to thin SiO_2 layers and metallic diffusion.

There were technical sessions covering many different aspects of semiconductor devices, from Bipolar Transistors through Noise in Devices, from Optoelectronic Materials to Non Volatile Memory Structures. I would have expected some sessions in the realm of device technology to deal with such topics as ion implantation or molecular beam epitaxy, but these did not materialize. Instead, contributed "technology" papers were limited to Silicon Processing and the details of processes for specific devices.

Nine invited papers either summarized work accomplished, of great current interest, or in closely related areas.

For years physicists have talked of quasi-two-dimensional crystals, yet only recently have they materialized. In the first invited talk, G. Landwehr (Max-Planck-Institut für Festkörperforschung, Hochfeld Labor, Grenoble, France—a joint French-German laboratory) pointed out that quasi-two-dimensional physics is now a reality thanks to the MOSFET, the metal-oxide-semiconductor-field-effect-transistor. This is because the gate field of a MOSFET confines charge carriers in the conducting channel to a layer with a thickness of the order of 50 Å or less. This phenomenon and others have made the MOSFET a most interesting tool of basic physics. Some of the phenomena or effects studied or utilized are two dimensionality; degeneracy of the electron gas at low temperatures, with variable Fermi energy; high mobility (up to 20,000 $cm^2/V\text{-}sec$); many-body effects (dependence of effective electron mass and g-factor on carrier concentration);

oscillations in conductivity with gate voltage; and such magnetic effects as the Shubnikov-de Haas oscillations in resistivity. Landwehr emphasized that high-quality devices, generally obtainable only from industrial research laboratories, are required for much of this research. He concluded his talk by suggesting that some of the basic physics work could find application in bolometric devices or infrared detectors.

In the first invited talk dealing with device matters, Prof. H.L. Hartnagel (until recently at the Univ. of Newcastle upon Tyne, UK, but now at the Technische Hochschule, Darmstadt, Germany) discussed results of his own work and that of others with metal-insulator-semiconductor (MIS) devices fabricated of gallium, arsenic, indium, and phosphorus (Ga, As, In, P). When perfected, such devices will find use in optical systems, for microwave amplification, and for gigabit logic.

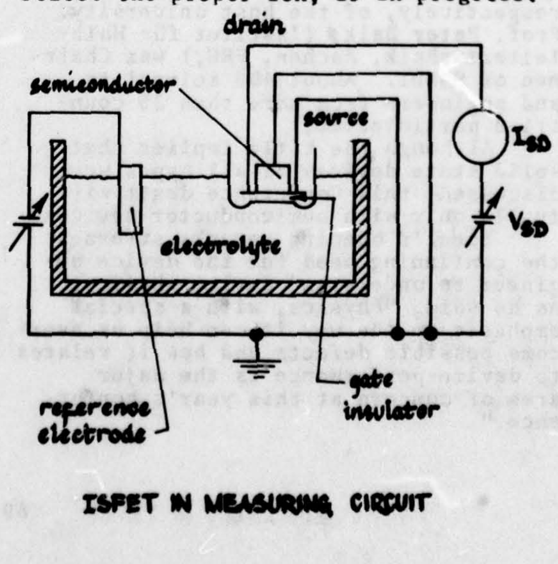
Hartnagel's talk dealt principally with insulating layers in GaAs and InP MISFETs.

One reason that integrated circuit technology is so well established is because silicon can grow a high quality native oxide (SiO_2). But silicon devices are limited by their relatively low carrier mobility and saturation velocity to frequency ranges below those possible with GaA and InP. And GaAs MESFETs (FETs with Schottky barrier gate) have the disadvantage in operation of possible destruction by forward gate bias. Then why not GaAs MOSFETs? They suffer from the fact that GaAs has a native oxide that is generally nonstoichiometric, full of traps, and has leakage currents, resulting in drifts in the operating point of a device and in limitations in large-signal cases, as in the pulsed-signal operation of logic circuits.

Hartnagel discussed the various attempts at growing MISFETs with insulating films on GaAs and InP, the difficulties encountered, the special techniques required for obtaining capacitance vs. voltage characteristics in the presence of electron trapping, and some device achievements. Specifically, oxide layers have been grown on GaAs by wet electrolysis and plasma anodization, and both Al_2O_3 and GaN have been deposited reactively. A successful method of fabricating InP MISFETs with much reduced surface state density (at Durham University, UK) has been the deposition of Langmuir-Blodgett amphipathic molecules on InP. Among the most notable device successes with GaAs MOSFETs are those reported from Japan: A depletion device of 1.8-μm gate length that oscillated at 22 GHz; a similar device that produced 0.4 W of output power at 6.5 GHz as a Class A amplifier; and an enhancement-mode FET with 11- or 13-dB power gain at 2 GHz, with a drop off of only 6 dB/octave.

In an ordinary FET the gate voltage is externally applied. It can also be caused by charge layers such as those that exist in electrolytes. Since the charge density in these layers is usually dependent on the ionic concentration, a FET can be used as an ionic concentration sensor.

Sensors of this type and related ones were the subject of the invited paper "Integrated Sensors," by M. Croset (Thomson-C.S.F., Orsay, France). According to Croset, recent developments of chemical sensors to conform with microelectronics technology have been: (1) Miniaturized classical macroscopic chemical sensors and (2) field effect sensors, of the type originally proposed by P. Bergveld in 1970 and now known as ISFETs. In one such ISFET, shown in the accompanying figure, the structure is that of an ordinary FET without metal gate electrode. The effective gate field, which controls current I_{SD}, is due to the electrolyte/gate insulator electrochemical interaction, plus that applied to the reference electrode. Work on such sensors, both with respect to integrating the reference electrode as well as in discovering membranes to cover the gate insulator and thus select the proper ion, is in progress.



ISFET IN MEASURING CIRCUIT

There has also been recent work on FET gas sensors. One type, sensitive to hydrogen, uses a palladium gate "electrode," thus making use of the strong diffusion of hydrogen through palladium to change the chemical potential and therefore the perpendicular field on the semiconductor.

Croset discussed these devices, other thin film chemical sensors, and the electrochemical effects that govern their behavior. He concluded that there is an increasing need for such devices and that sensitivity, selectivity, reversibility, and time response of microelectronic sensors appear to be satisfactory. Practical devices will require improvements in lifetimes and increase in range of detected ion species.

One ISFET device, a p-channel depletion mode silicon ISFET, was discussed by E. Kobierska, J. Gautier, and M. Montier (Grenoble, France). With the 500-Å gate oxide (SiO_2) as ion sensitive material and a calomel reference electrode, the pH of various acid and base solutions could be measured, with ΔV_{SD} (see figure) of 100-200 mV. per pH unit. The device was said to be stable for at least three months but was temperature sensitive. The authors suggested that future work should aim at the use of glasses other than SiO_2 and at the deposition of other ion-selective membranes.

Results on another type of structure, a silicon tunnel diode with a very thin platinum electrode (<100 Å) covered with a 25-Å layer of SiO_2 and sensitive to CO_2 and CO gas, were disclosed by J.P. Dauchot (Mons, Belgium). By monitoring the resistance of this diode, it was possible to detect a few tens of ppm of CO, with a response rate depending on the metal thickness.

The move toward putting more and more circuits on a chip (VLSI) and toward faster logic circuits gave rise to two invited papers. F.M. Klaasen (Philips, Eindhoven, the Netherlands) considered the factors limiting the operation of very small devices, in which by a "device" he referred to a logic circuit configuration such as ECL, I^2L, and others. In his approach, he defined a technology in terms of a set of impurity distributions, oxide layer thickness, etc., and the related electrical parameters. Next, lateral dimensions were taken into account and, with the aid of a geometrical device model, electrical model parameters were generated, for use in a circuit simulation program.

By comparing speed, dissipation, and packing density, he predicted a substantial improvement in performance for every technology, with MOS benefitting most from down-scaling to 0.5 µm. ED-MOS will eventually rival ECL in speed and I^2L in speed-power product. I^2L will become the slowest technology but have the best packing density. Current densities in MOS will approach those of ECL.

The factors and problems encountered in micron-size lithography were discussed by S. Broydo (Bell Laboratories, Murray Hill, N.J.). He listed these factors as projected image resolution, photoresist properties, photoresist thickness, registration accuracy, mask and wafer distortion, defect density, and cost.

According to physical optical principles, the resolution limit is (1.2) (λ)(F), where λ is the wavelength and F the f-number of the lens system. It is this limitation that has led to the more difficult technologies using x-rays or EBES (Electron Beam Direct Exposure).

Difficulties encountered in x-ray lithography are that special masks are required to compensate for the fact that x-rays emanate from a point source (There are no good x-ray lenses!), that the photoresist is a problem, and that the mask-wafer combination must be ultra-flat.

EBES requires no mask and is therefore not limited by mask defects, has fantastic resolution, can compensate for some distortions, but has one great difficulty: It takes forever! Actually, about an hour is required for each wafer. There are also problems that call for improvements in the photoresist and methods of etching it.

Broydo concluded by stating that work is in progress on shaped electron beams, higher currents, and other aspects of the technology.

The picture painted led Prof. Balk to remark, "Apparently not all of the problems that plague us here have been solved on the other side of the Atlantic."

Leading off the sessions dealing with random fluctuations of currents in semiconductors, i.e, noise, Professor R.J.J. Zijlstra (Rijksuniversiteit, Utrecht, the Netherlands) presented a review of Noise in Devices. His paper dealt with thermal/diffusion noise associated with velocity fluctuations (including hot carrier effects), shot noise, generation-recombination noise, 1/f noise, the flux flow noise occurring

in superconducting materials, and experiments in which noise measurements can be used as a tool for material investigations.

Among the contributed papers, M.J. Sisson and P.A. Houston (GEC Hirst Research Centre, Wembley, Mddx, UK) and A.J. Grant, A.M. White, and B. Day (Royal Signals and Radar Est., Great Malvern, UK) discussed low-frequency noise in GaAs and InP devices. By correlating noise measurements with results from deep-level transient spectroscopy (DLTS), it now appears most likely that 1/f noise is due to deep traps in the diode depletion region. Moreover, a simple indication of whether a Schottky diode can be expected to be noisy is a look at the ideality factor "n" of the diode I-V characteristic. A high value of "n" signifies a high noise level. Sisson and Houston have found that the density of deep traps in GaAs grown epitaxially from a liquid (LPE) was considerably less than those grown from the vapor phase (VPE), with a resulting improvement in noise of 20 dB.

Shifting now to Optoelectronics, we come to the semiconductor laser, reviewed by P.R. Selway [Standard Telecommunication Laboratories Ltd., (STL) Harlow, UK]. Initially requiring liquid nitrogen cooling, a current of around 100 A (pulsed), and lasting less than 10 hours, semiconductor lasers now, 16 years later, operate cw at room temperature, with currents down to fractions of an ampere, and with a predicted lifetime of up to 100 years. A typical structure is: n-GaAs, n-GaAlAs, p-GaAlAs, p-GaAs, with the composition (and therefore refractive index) of the GaAlAs chosen to have the desired bandgap for the wavelength emitted and to maintain light trapping to a thickness of approximately one wavelength.

Because the region of zero dispersion for optical fibers has been identified as 1.3 μm, it is to this wavelength that much of the laser diode work has shifted.

Selway discussed various aspects of the technology. Examples are: (1) A (GaIn)P active region—not yet materialized; (2) molecular beam epitaxy (MBE) method of layer growth—unsatisfactory because of high trap density; (3) VPE method of layer growth (at Rockwell)—a most exciting recent development promising longer life; (4) beam narrowing, with stripe laser configuration, yielding a 50° × 5° beam; (5) photo-elastic waveguiding.

In a related contributed paper G.D. Henshall, G.H.B. Thompson, J.E.A. Whiteaway, P.R. Selway, and M. Broomfield, (STL, Harlow, UK) discussed 2.5-MeV proton bombardment to isolate sections of the active region both electrically and optically in laser structures at a depth of 40 μm. Such structures are used for high peak power lasers, with the proton-isolated structure offering a number of advantages over sawn-cavity lasers.

Continuing with technology, now in more general terms, brings us to "Low Pressure Chemical Vapor Deposition," in which J.P. Duchemin (Thomson-CSF, Orsay, France) described work dealing with the deposition of semiconductors (e.g., doped silicon) or insulating layers (e.g., Si_3N_4) on substrates held under various degrees of vacuum. Advantages given for this low pressure method of deposition are: (1) Reduction of "memory" effects, auto doping, and parasitic nucleation—especially important for GaAs. (2) Lowering of the temperature required for either growth or etching by rendering the chemical reactions possible by radio-frequency glow discharge. (3) Economy (increase in the number of substrates processed per run, through vertical positioning; increase of uniformity; decrease of gas used per wafer).

Duchemin's summary of chemical vapor or etching deposition (CVD) under various vacuum ranges is given in the following table:

	Pressure Range Torr	Deposition or Etching	Gas Phase Composition
Intermediate Pressure Deposition (IPCVD)	10-200	Si epitaxy	$Si\,H_4 - Si\,H_2\,Cl_2$ H_2
	30-200	Ga As epitaxy	$Ga\,(CH_3)_3$ $As\,H_3$ H_2
	30-200	InP epitaxy	$In\,(C_2H_5)_3$ PH_3 H_2N_2
		Ga in AsP	$Ga\,(CH_3)_3 - In\,(C_2H_5)_3$ $AsH_3 - PH_3$ $H_2 - N_2$
Plasma-Enhanced Etching	0.1-1	$Si\,O_2$ Si_3N_4 Si	CF_4
Plasma Enhanced Deposition (PECVD)	0.1-1	Amorphous Si Si_3N_4 (Plasma)	$Si\,H_4 - Ar$ $Si\,H_4 - NH_3 - Ar$
Low Pressure Deposition (LPCVD)	0.1-1	poly Si Si_3N_4 SiO_2	SiH_4 or $SiH_2Cl_2 \cdot N_2$ SiH_4 or $SiH_2Cl_2 - NH_3$ $SiO_2 - N_2O - N_2$

I have already mentioned in the early part of this summary that this was a semiconductor meeting. Just to make the participants aware of what the competition is doing, Dr. P. Coeuré (LETI/EPA, Grenoble, France), reviewed magnetic bubble technology. Although slower than semiconductor memories in information transfer, bubbles have the advantage of nonvolatility. They are also of low cost and highly reliable.

Magnetic bubbles have been reviewed a number of times since their invention in 1967. I shall therefore not discuss their operation here but shall mention that according to Coeuré, "bubbles" became commercially available in 1977, that Rockwell International and Texas Instruments are said to offer a 256 K bit chip in 1979, and that 1 M bit chips are projected for 1980.

In this brief summary it is obviously not possible to review the other 130 papers. Instead, I will mention a few additional specific contributions, then list some of the other subjects covered.

C. Tsironis (Tech. Univ. of Aachen, Germany) discussed studies of the dependence of the channel structure of GaAs MESFETs (for microwave amplification) on noise and substrate breakdown. He found that outdiffusion and arsenic vacancies on the substrate surface degrade mobility, thereby reducing transconductance and increasing device noise figure. Some improvements were found by growth of a buffer layer.

In another investigation of substrate and interface effects in GaAs, H. Transduc, P. Rossel, J. Graffeuil, C. Azizi (CNRS, Toulouse, France) and G. Nuzillat and G. Bert (Thomson-CSF, Orsay, France) presented experimental C-V and I-V plots for GaAs FETs made of a Cr-Fe doped substrate and an active thin N-layer grown by an organometallic "cracking" epitaxial process. An analysis led to methods of obtaining the parameters of the N-active layer and the interface parameters from device behavior.

Despite the success of GaAsFETs, don't count silicon out yet as a contender for high speed FET applications! For U. Niggebrugge et al. (Aachen, Germany) reported on the construction of a silicon MOSFET with 44 ps switching time and 50 ps delay time. While the device certainly cannot compete with GaAs in frequency range, it could become a competitor at lower microwave frequencies, because of the much simpler silicon processing.

Among reports of other novel devices was the announcement by A. Deneuville (CNRS, Grenoble, France) and M.H. Brodsky (IBM, Yorktown Heights, NY) of successful achievement of a metal base transistor composed of hydrogenated amorphous silicon emitter and collector and a 90-Å thick platinum base. Although this device had an injection efficiency of only 8%, it did exhibit transistor-type behavior.

Finally, in addition to papers dealing with subjects already mentioned, there were sessions treating Modelling, Silicon on Sapphire, Photodetectors, Display Devices, Photoemitters, Bipolar and Silicon MOS Transistors, Charge Coupled Devices, Power Devices, Defects and Characterization, and Memory Structures. It was announced that contributed papers, if submitted and accepted for publication, would be published in *Revue de Physique Appliquée*, and that a special issue of this journal was set aside for the invited papers.

Last, but not least, I must mention that the social program of the Conference surpassed anything of that type that I have ever experienced in the US. The banquet for the 400 or so attendees was held in the Great Hall of the Palace of Popes, in the neighboring city of Avignon. It was a medieval feast, complete with trumpet fanfares, horses, wandering minstrels, jugglers, fire-eaters, and of course, excellent French food and drink. I think even Hollywood could take lessons from the French! The organizers of next year's conference, in Munich, must be racking their brains now to try to top that event. (Irving Kaufman)

SAFER JOINTS-WELDING IN NUCLEAR ENGINEERING

The 3rd International Conference on Welding in Nuclear Engineering took place 28-29 November 1978 in Hamburg, FRG. This meeting is convened every four years by the German Welding Society, the previous meetings having been in Dusseldorf in 1974 and Frankfurt/Main in 1970. The Conference attracted nearly a thousand participants, nearly all from Germany and other European countries. Ten countries contributed papers, but only 2 were from the US and none from the UK. The program of 6 plenary addresses and 50 short papers was divided into 5 headings: Quality Assurance, Welding Technology, New Welding

Procedures, Materials R&D, and New Testing Methods. The first and last areas will be virtually neglected, this report emphasizing the metallurgical engineering content of the program.

The organizers must have had a very hard time putting the papers into these neat categories, because a great many related to several topics at once. Put another way, the engineers and scientists in this field must of necessity be simultaneously concerned about variations in welding procedures and their effects on the materials being welded. The related topics of testing and quality assurance, which this note will tend to overlook, are, of course, an essential part of this integrated approach to a complex, classical metallurgical engineering relationship of design, materials, fabrication, and inspection.

The six plenary lectures covered the usual hackneyed topics such as "The Importance of Nuclear Energy for Securing the Future Energy Supply" and "Reactor Safety and Environmental Impact," etc., and while these are important and interesting subjects, I feel fortunate that I am responsible for only the material sciences aspects which are less controversial. However, before putting the blinders on to the political and social issues, it should be acknowledged that much of the technical content of the Conference was closely allied to the theme of reactor safety and environmental impact, and an abundance of interesting relevant discussions were offered. Economics also comes in, and welding is calculated to account for around 40% of the production costs of a container for a boiling water reactor (BWR). Therefore, in addition to the basic technical problems, we have cost and safety as overriding factors in welding for nuclear engineering.

The papers presented at the Conference covered the gamut from basic materials and filler metals to material properties, welding and brazing procedures, quality control, failure analysis, welding process development, and equipment. The common thread was welding process/materials properties relationships. Welding virtually always changes materials properties, and there is probably no known example where the change is in a favorable direction. There is a long list of deleterious effects including embrittlement, weakening, creation of residual stresses, cracking, etc. Engineers faced with this phenomenology often overlook the connecting aspect of the process/properties correlation, namely the metallurgical microstructure, which is changed by welding and so in turn changes the properties. Some of the papers considered the total picture, with attention to the microstructural effects, while others limited their attention to the effects on properties. This note will tend to emphasize those discussions that used the more complete treatment of the welding/microstructure/properties situation.

In the session called "Materials R&D" most of the papers had to do with physical metallurgy problems that commonly crop up in nuclear welding. The majority were microstructure-properties studies of welded nuclear structural materials such as ferrous pressure vessel alloys. Before going on to a survey of some of the more interesting papers, it is perhaps appropriate to insert a very brief review of one of the key concepts of welding metallurgy, namely the weld heat-affected zone (HAZ), which comes into consideration in most of the problems associated with welding.

Regions of base metal adjacent to a weld are known as the heat-affected zones because of the microstructural changes that occur due to the heating and cooling excursion that accompanies welding. In steels, this thermal cycle tends to coarsen the grain structure at high temperature, then transforms it to very hard, brittle martensite during rapid cooling. The low alloy steels used for nuclear reactor pressure vessels usually have carbon concentrations sufficiently high that the martensitic microstructure is indeed quite brittle in the HAZ. It is therefore desirable to modify this as-welded condition, such as by a post-weld heat treatment to temper the martensitic transformation products and to relax weld-induced residual stresses.

One of the prominent problems in welding nuclear pressure vessels is "reheat cracking." Several papers considered this problem. Cracking of low alloy steels tends to occur in the HAZ near strength welds during stress-relief heat treatments of the welded structure. In some instançes it has been found that the coarsened grain structure of the HAZ has such poor ductility in the range around 600°C that even the small creep deformations necessary to relax the residual stresses cannot be accommodated.

It is generally assumed that such a thermal stress relaxation occurs by uniform distribution of the creep strain throughout the welded structure. However, research reported by A. Dhooge and A. Vinckier (Univ. of Ghent, Belgium) has shown that locally very high creep strains may develop, especially at stress concentrations, fillet welds, changes in cross section, etc, if these sites also happen to be locations with high residual tensile stresses. Also, it has been shown that areas with residual compressive stresses, which balance the adjacent areas with tensile stresses, always recover in a purely elastic manner; but this process provides additional creep strain to the tension regions and thus contributes to cracking. Having provided evidence of this mechanism, Dhooge and Vinckier have developed a small welded test specimen that can be used to evaluate susceptibility to reheat cracking while under load in a bending jig.

Another cracking problem, known as "hot cracking", plagues iron-nickel-based superalloys such as Alloy 800. This is a widely used material for critical nuclear applications. The hot cracking problem has been associated with impurity and trace elements. Since beneficial effects of high Mn and low Si are well known for austenitic stainless steels, an investigation reported by B. Lundquist and coworkers (Sandvik AG, Sandviken, Sweden) was undertaken to see if these effects are also valid for iron-nickel-base alloys such as Alloy 800, and to observe the effect of alloy dilution, as for example when welding an iron-nickel-base alloy to austenitic stainless steel. ASTM specification B 163 specifies the Mn and Si contents of Alloy 800 to be 1.50% and 1.00% maximum, respectively. The main reason for the increased cracking resistance with high Mn and low Si is thought to be associated with reduced TiC/Ti(C,N) precipitation at grain boundaries and/or reduced segregation of Si. A third cracking problem is "cold cracking" after welding. J. Schmidt and coworkers (Kraftwerk Union, A.G., Erlangen, FRG) discussed failure analysis and prevention methods for cold cracking in attachment welds, fillet welds, and claddings.

The sessions on "Welding Technology" and "New Welding Procedures" covered similar aspects of the nuclear welding field. These sessions included discussions of cute twists that have been applied to proven welding techniques and evaluated in actual service situations, as well as ideas that are still in the development stage. Quite a few of these papers also dealt with the reheat cracking/HAZ problems already mentioned. D.A. Canonico (Oak Ridge National Laboratory, Oak Ridge, TN) discussed the "half-bead" weld procedure commonly used when weld-repairing thick-welded nuclear pressure vessels. This is a technique used because a normal stress relief cannot be applied at site. In the "half-bead" method the first weld bead is ground off about 50% so that the laying down of a second bead can cause an effective stress-relief heat treatment of the bead below and its HAZ. Canonico's discussion of this method included a consideration of the effects of the procedure on the fracture toughness of the HAZ. On the same method, W. Goins and E. Merrik (Tennessee Valley Authority, Chattanooga, TN) discussed experience with the use of the half-bead weld repair method in actual situations, with caution to its application in very deep weld repairs.

Unfortunately the two-step "half-bead" procedure is costly and time consuming, and especially the cost of filler metal is high. Because of this, alternative methods have been developed, such as high-frequency heating and TIG (tungsten inert gas) remelting of the surface without addition of more weld metal. For various reasons these techniques have not been widely applied, and in the "New Procedures" session another method to accomplish the same task was proposed by M. Areskoug and H. Widgren (AGA AB, Lidingo, Sweden), namely, the ability of the gas-metal-plasma-arc (GMPA) process to influence the HAZ of weld cladding. With separate heating circuits to control independently the heat input to the base and filler metals, microstructural control is enhanced. Work on this method was also presented by Prof. J. Ruge (Technical Univ., Braunschweig, FRG), including detailed metallographic, mechanical and corrosion properties studies.

Yet another scheme related to weld residual stress was proposed by K. Imai and coworkers (Babcock-Hitachi K.K., Hitachi-shi, Japan). Their scheme approaches the problem by attempting to prevent residual stresses during welding rather than trying to remove them afterwards. This has been approached in

the case of pipe welding by the seemingly simple technique of cooling by running water on the inside of the pipes (after the first weld pass, of course). This mitigates both unfavorable residual stress development and microstructural sensitization, so that IGSCC susceptibility is lowered. One of the reasons for this is that the weld residual stress in the HAZ becomes compressive using this procedure. A related paper, from D. Cicclov and P. Bozu (Institute of Welding and Metal Testing, Timisoara, Romania) described the assessment of weld reheat cracking tendency by means of short-time creep tests of various candidate alloys.

Naturally at a conference of this sort, numerous papers were presented that were only slightly concerned with materials aspects, but were quite interesting from a technological standpoint. Two in this category on remote-controlled welding were presented by S. Kokura and coworkers (Hitachi Ltd, Tokyo, Japan) and by K.N. Eindhoven and coworkers (Metal Research Institute TNO, Apeldoorn, the Netherlands). The Hitachi equipment was developed for pipe welding and includes a video camera attached to the welding head for monitoring only, with computer control of weld head movement and welding conditions. The TNO work, also including a video system, was applied to welding of stainless-steel heat-exchanger shells in the nuclear environment, in this case with direct operator control of the process with the aid of the TV. In other papers of particular interest E. Shibato and coworkers (Hitachi Ltd, Hitachi-shi, Japan) reported development of a new tube-to-tubesheet welding method for heat exchangers in fast breeder reactors (FBR).

Two papers, from G. Sayogh and coworkers (Sciaky S.A., Vitry-sur-Seine, France) and W. Hiller and K.H. Steigerwald (Steigerwald Strahltechnik GmbH, München-Puchheim, FPG) reported on recent developments in the application of electron beam welding (EBW) methods in the nuclear industry. Although EBW has been developed and used quite extensively over the last 20 years in light applications in the aeronautics, automotive, and nuclear areas, heavy industrial welding applications have been few. Reluctance to adopt this method is due in part to difficulties in introducing a sophisticated technique into a traditional field, and because the EBW equipment available doesn't suit the needs of heavy industry. These needs include welding large cumbersome components difficult to introduce into an EBW welding chamber and welding of heavy sections. Another problem is that generally the quality of the steels used are not the best suited for EBW. Also, the condition of the surfaces must be quite good; flame-cut edges are not sufficient, so that machining of the workpiece is required. However, in the last few years developments in the EBW field have brought the technique much closer to widespread application, with the first forseeable applications being to stainless steels, some low alloy steels, and aluminum alloys.

As pointed out earlier, the Conference tended to emphasize the connections between welding procedures and metallurgical structures and properties. As is so often the case in high technology, successful developments of new equipment or processes are critically dependent on the quality of the materials and their ability to be fabricated. The nuclear field is certainly a prime example of this, with the presence of two dominant nontechnical factors, cost and safety, both closely related to the purely material aspects. The metallurgical principles at this Conference were presented in a very practical context; there was virtually no science for science's sake, but there were numerous examples of the advancement of metallurgical engineering frontiers through the application of sound microstructure-properties studies. (Jeff Perkins)

MATERIAL SCIENCES

POLYMER CRYSTALS

The crystalline nature of many commercially important polymers such as polyethylene (PE), polyvinychloride (PVC), natural and synthetic rubbers, and polyethylene terephthalate (PET) dictates their strength, durability, and processability. Considerable research on polymer crystallization is underway in the UK and on the Continent, an overview of which was published here earlier (*ESN* 32-8: 271).

A recent conference, Crystalline Polymers; Structure and Properties, brought to light some of the controversy and unanswered questions that currently exist in this area of polymer science. The conference was held in London on 14 December 1978 and was sponsored by the Plastics and Rubber Institute.

The morning session was chaired by Prof. Anthony Keller (Univ. of Bristol) who also gave the opening lecture. Keller made the general observation, shared by most workers in the field, that crystalline polymers must be thought of as composites made of crystal domains having one or more morphologies along with regions of amorphous polymer. The organization, size and structure of these various regions dictate the properties of the polymer. Deliberate efforts to attain a specific overall morphology can result in very desirable properties, but failure to control morphology can have ruinous consequences.

In quiescent melts, linear polymers *such as PE form lamella in which* most workers believe the molecules are chain folded with the folds perpendicular to the plane of the lamella. Actually, the argument for a chain folded structure is best made for lamella grown from solution. It is presumed that the same chain folding occurs for lamellae formed from melts.

The lower the supercooling (high crystallization temperature) the thicker the lamellae. At extremely high supercooling (quenching) the "fringe micelle" structure forms in which a few hundred molecules arrange themselves into bundles of parallel chains (Fig. 1). Most of the quenched solid is amorphous.

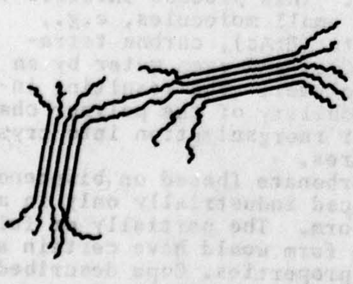


Fig.1.

In flowing melts, fibrous crystals form as a result of localized chain extension. Keller emphasized the need for chain extension in order to obtain fibrous structures. In most practical situations both quiescent and flow conditions exist so that both fibers and lamella are formed. A special case of a mixed structure is the shish kebab structure of alternating lamellae and fibers (see *ESN* 32-8:273). Keller proceeded to describe some of the work of his group at Bristol. In melts of commercial PE with a large spread in molecular weight (MW) distribution, *isothermal* crystallization leaves a significant fraction of low MW polymer remaining liquid. When the sample is brought to room temperature, this liquid is strongly supercooled and solidifies to form very thin lamellae. The resulting composite has properties quite different from that obtained by similar cooling of PE melts with a highly monodispersed MW.

The Bristol group has found that in PE melts with a high density of crystallizing nuclei (as in commercial PEs) the solidified polymer has a fine texture of spherulites but that the lamellae which form the spherulites are relatively thick.

Keller closed his talk by describing a very significant discovery in controlled polymer morphology. He has been able by flow melt techniques to tailor the shish kebab morphology so that the crystallites interlock. The result is a high modulus polymer with low thermal shrinkage and resistance to fibrillation.

In the second paper Dr. A.M. Hodge (Univ. of Reading) described some recent work on the microscopy of polymer crystal structure. He uses a staining technique developed by G. Zanig [*Kollid Z.* 251, 782 (1973)] in which the polymer is treated with sulfuryl chloride which introduces electron dense atoms (S and Cl) to the lamellae surfaces so that they appear outlined in the electron microscope. Hodge and his colleagues have developed an etching technique for PE, polypropylene and poly(4 methyl pentene-1) using aqueous permanganic solution.

Using this etching technique and chlorosulfonate staining, Hodge has found some unexpected morphology in crystalline PE. Low MW polymer that has been cooled slowly develops a structure of ridged sheets (Fig. 2) organized

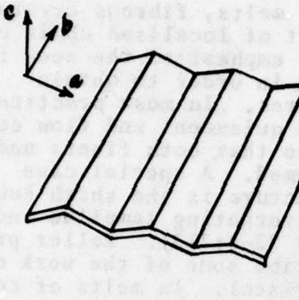


Fig. 2.

into the expected spherulitic pattern. At high MW and/or low crystallization temperatures, the alternating slope disappears and more planar sheets form. At MW > 10^6 and in all quenched samples, S-shaped lamella form (Fig. 3). The interstitial region between the S-sheets is filled with planar crystals.

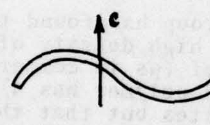


Fig. 3.

Hodge suggests that these results are in qualitative but not quantitative agreement with the Keith and Padden theory of spherulitic growth [*J. Appl. Phys.* 34, 2409 (1964)]. He also concludes that the model of banded spherulites [banding being due to continuous rotation of the c-axis about the growth (b-axis) direction] is not the result of helicoidally twisted lamellar ribbons. Instead, the lamellae texture is a complicated multi-connected one within which S-shaped sheets are dominant, and over large fractions of the band period, these are untwisted but then undergo sudden changes in azimuth to allow continuous rotation of the average molecular orientation.

Dr. W.F. Maddams (British Petroleum Group, R&D Centre, Sunbury-on-Thames) reviewed the techniques currently used to measure the degree of crystallinity in polymers. These include x-ray diffraction, infrared spectroscopy (IR), Raman spectroscopy, broad line nuclear magnetic resonance (NMR), density measurement, and differential scanning calorimetry (DSC). As might be expected, no one method is universally applicable and each has its pitfalls in interpretation.

X-ray diffraction is most widely used, but Maddams pointed out that for many commercial polymers, e.g., PVC, the multiple diffraction peaks are not easily separated from the amorphous scattering curve. The problem in using IR is in identifying bands that are truly crystal related; bands caused by interaction between neighboring chains in the crystal unit cell. Raman spectroscopy suffers the same problems as IR. Broad-line NMR can be very misleading. The interpretation of broad and narrow bands as indicative of crystal and amorphous components, respectively, is too simplistic. Maddams cited the case of PE which at ambient temperature exhibits two bands but when the temperature is lowered appears to be 100% crystalline.

Specific volume measurements and DSC require calibration; the density and DSC response of the pure crystalline phase must be known. If data for the pure crystal can be obtained, Maddams considers both techniques can be useful in differentiating crystal phases that differ only slightly in structure.

Maddams made two general points. First, that in any in-depth study of crystal structure, as many techniques as possible should be used since the results from one can be too easily misinterpreted. Secondly, on the present industrial scene, there is a tendency to overkill in determining crystallinity especially when its significance to processing or properties is not well established.

Dr. B.C. Cope (Leicester Polytechnic) described his work with Dr. J. C Comyn on solvent induced crystallization of polymers. This process involves the sorption of small molecules, e.g., ethyl acetate (EtAc), carbon tetrachloride (CCl_4) and even water by an amorphous polymer. The resulting increase in mobility of the polymer chains allows their reorganization into crystal structures.

Polycarbonate (based on bisphenol-A) is produced industrially only in an amorphous form. The partially or fully crystalline form would have certain advantageous properties. Cope described their work on the sorption and crystallization of PC with EtAc and CCl_4 from the vapor and liquid phases. Using a vacuum micro-balance, they followed

vapor uptake as a function of the vapor concentration (activity) of the penetrant. At some critical activity, which depended on the penetrant and the temperature, there was a rapid sorption followed by a spontaneous desorption caused when the developing crystals expel the penetrant. Below the critical activity, there was no detectable sorption of the penetrant.

Residual amounts of penetrant were tenatiously held by the polymer and could not be removed without altering the crystal structure. This residual solvent interfered with the measurement of the degree of crystallinity. However, using DSC and density measurements, the Leicester workers estimated that the EtAc and CCl_4 induced 30% and 50% crystallinity respectively in PC. Microscopic examination of films of the treated PC revealed spherulite structure and considerable voids and cracks in the surface.

Dr. P.J. Hendra (Univ. of Southampton) livened the meeting somewhat by challenging the folded chain model for the structure of PE *crystal lamellae.* He pointed out that chain folds have not actually been observed and that theory, based on the concept of chain folding, explains most but not all experimental results.

Hendra's Raman spectroscopy studies on the crystal dimensions in PE led him to suggest that the meandering chain form is more prevalent than generally believed. Melts of PE quenched rapidly to 170 K form an amorphous glass. If allowed to warm to 293 K, the PE forms crystal lamellae having the same thickness as those formed by slow cooling of melts and would then be presumed to have a chain-folded structure. Hendra asks, how do the long PE chains attain the mobility to rearrange into folds on simply warming the amorphous glass to a temperature well below the melting point? Actually, he finds evidence for structure in the quenched glass and that the apparent lamella thickness in the glass is essentially the same as in the crystalline solid.

The effect of melting temperature on lamella thickness has also been studied by Hendra using Raman spectroscopy. In general, the higher the melting temperature the larger the lamella thickness. The degree of supercooling was the same. That there should be any crystal dimension dependence on melting temperature suggests some persistence of order in the melt but that chain folding could persist seems, to Hendra, unreasonable. Actually, he points out that the great majority of the evidence in the literature indicates that the chains in PE melts are randomly oriented. Hendra then suggests that at cross-over points in the melt, the chains tend to align with one another as the melt cools. Such a process leads to the meandering chain structure (Fig. 4).

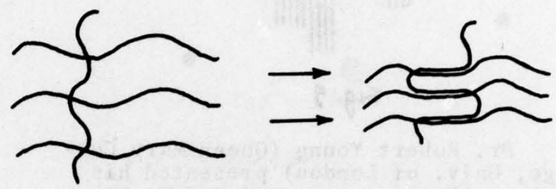


Fig. 4.

The afternoon session was chaired by Prof. I. Ward (Univ. of Leeds) who has been a leader in the development of high modulus polymer fibers. These fibers are formed by melt drawing so as to align the molecular chains in the draw direction. Moduli of up to nearly 5×10^2 GPa have been attained which approximates the modulus of steel.

Ward began the session with a few comments on high modulus polymer fibers, noting some of their history and properties. He closed by suggesting that it is necessary to understand the disordered regions of polymer fibers in order to understand the ordered regions.

One of Ward's co-workers, Dr. A.G. Gibson (Univ. of Leeds) gave the first afternoon paper which generally covered their thinking on the morphology of ultra-oriented polyethylene. The problem is to account quantitatively for the observed moduli in terms of some distribution of crystalline and amorphous regions. Obviously, any model that puts the low-modulus disordered regions in series with the crystallites along the fiber axis is quite inadequate. Nor can tie chains between crystal regions account for the observed stiffness. The group at Leeds favor a structure in which there are crystal bridges between crystallites through the amorphous regions. (Fig. 5) More precisely, they view the ultra-oriented fibers as a composite of short crystal fibers in a matrix of small crystals and amorphous

polymer. With this model they can quantitatively account for the observed modulus.

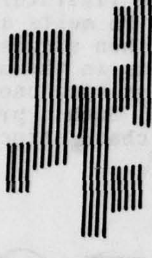


Fig. 5

Dr. Robert Young (Queen Mary College, Univ. of London) presented his work on the structure and deformation of polydiacetylenes which was described here recently (*ESN* 33-1:14) These are highly ordered, near perfect polymer crystals that can be formed into short fibers with the molecules parallel to the fiber length. Moduli up to 50 GPa are theoretically possible for these fibers but have not yet been attained. Young believes modifications of the diacetylene monomer can be made which will give higher fiber stiffness.

Dr. C.K.L. Davies (Queen Mary College, Univ. of London) has been studying the effect of pressure on the crystallization rate of trans-1, 4-polyisoprene. It is well known that at high pressures, polymer melts crystallize very rapidly to form thick, chain-extended crystals. However, it is not clear why growth should be so rapid under pressure compared to the rate at atmospheric pressure under the same degree of supercooling.

Davies has studied polyisoprene at pressure below those at which it forms chain-extended crystals. He finds that the growth rate actually decreases with increasing pressure from 1 atm up to 35 kbar. This observation implies that no crystals should form at higher pressures, contrary to what is observed. Davies suggests that at high pressures there is a compression of the melt which causes a preorientation of the polymer followed by rapid incorporation into thick crystals.

It was clear from this meeting that there is a general understanding of the nature of polymer crystals, but some important details are still controversial or simply not understood at all. Among the issues to be resolved is the validity of the chain fold model, especially for crystals formed from melts, the degree of order in the melts themselves and the crystal morphology of melt grown crystals (such as spherulites) and ultra-oriented fibers. Also, much of the research has been done on PE, a relatively simple molecule. More complex polymers will undoubtedly present even more difficult questions. (Willard D. Bascom)

SURFACE SCIENCE AT THE UNIVERSITY OF YORK

The city of York is a microcosm of English history with evidence of its Roman origin, occupation by the Danes, and participation in all the triumphs and follies of the English Monarchy. Unlike the cities of Oxford, Cambridge, and London, York did not flourish as an educational center. Ostensibly, the reason was Henry VIII's closure of the church-controlled schools and ministries as part of his break with Rome, but economic factors also played a role. Almost 400 years later, in 1963, York reinstated itself as a center for learning when a sprawling modern university was built about two miles outside the city wall. There is a striking contrast between the ultra-modern architecture of the university and the medieval flavor of the city.

A one-day meeting was held at the University on Structure Analysis for Surfaces in December of 1978 under the auspices of the Institute of Physics. In some respects it was a showcase for surface science research in the Department of Physics at York. The meeting began with a tour of the surface analysis facilities. We were shown a scanning Auger spectrometer in early stages of construction. When completed, this instrument will give visual representation of the atomic distribution on solid surfaces with a resolution of 200 Å. The highlight of the tour was the low energy electron diffraction (LEED) equipment with photoelectronic capability to monitor the intensity of individual spots on the diffraction pattern. Also exhibited were equipment for conventional Auger spectroscopy and photoelectron emission spectroscopy (PES).

All of the equipment had been built inhouse, and much of the data collection and analysis was computer controlled.

The morning session of the conference was chaired by Dr. J. Beebe (Univ. of Leicester), and the first paper was on Angle Resolved Photoemission for Structure Analysis by Prof. D.A. King (Univ. of Liverpool). King cited the objectives of angle-resolved PES, and indeed of all the surface analysis techniques described at this meeting, to be the determination of the electronic states of surface atoms both in energy and space. This objective goes beyond the simple determination of surface chemical composition.

In PES, incident x-ray radiation ejects electrons from the surface atoms and the energy of the emitted electrons is determined by the atomic orbital from which they came. In angle-resolved PES the angle of incidence of the x-rays is varied, and, from an analysis of the angular dependence of the emitted electron energy, a map is obtained of the electronic orbitals on the surface. King discussed the case of carbon monoxide (CO) adsorbed on ruthenium [100] where it was found that the adsorbate molecule was held at a 20° angle to the metal surface. Also described was the mapping of the surface electron state densities on metals by the diffraction of the emitted electron wave to give an interference pattern of the electron orbitals of surface atoms. An example of the electron wave diffraction was a study of tellurium atoms on tellurium selenide. The results agreed well with existing theoretical models of this crystal surface.

Dr. P. Carr (Univ. of Oxford) talked on Angle Resolved Auger Spectroscopy Applied to the Study of Various Overlayer Systems on Amorphous Silicon. Here, as with PES, the incident beam is x-rays which along with photoemitted electrons also cause emission of Auger electrons. Auger electrons result from outer electrons falling into the lower energy orbitals from which the photoemitted electrons were ejected. The Auger electrons usually come only from the top layers of the solid thus making this spectroscopy very surface specific. Carr described a study on pure silicon where the angle of incidence of the x-ray beam was varied through 180°. The Auger intensity of the LLV transition varied as $\cos^2\theta$ with maximum intensity at normal incidence (θ=90°). This angular distribution of intensity is distorted if there is an adsorbed layer, e.g., carbon contamination, and for Si in different chemical environments (elemental Si vs SiO_2).

Dr. D.G. Armour (Univ. of Salford) described the use of Low Energy Ion Scattering for Surface Structure Analysis. In this technique argon (Ar) or neon (Ne) ion beams impinge on the solid and are scattered by the surface atoms. The energy of the scattered ions depends on the mass of the scattering atom, and by scanning the energy of the reflected ions a spectrometric analysis of surface composition is obtained. Each different atom on the surface give a maximum in scattering yield at different energies. For a given surface atom, the scattering yield may show two maxima; one at low energies corresponding to the collision of the ion with only one surface atom (quasi-single scattering, QS) and the second at higher energies corresponding to collision with two surface atoms (quasi-double scattering, QD). As might be expected, the QD scattering peak increases with closer spacing of the surface atoms and may become larger than the QS peak at very short spacings. Also, the QS and QD peaks shift in energy as the angle of incidence of the ion beam changes. At very low (grazing) angles, there appears to be channeling of the ions along potential energy wells in the surface between rows of atoms.

Armour described the use of the Ne^+ and Ar^+ beam scattering in a study of oxygen adsorption on nickel. At low coverages the adsorbed O gives a weak broad peak in scattering yield at low energies and at higher energies the QS and QD peaks for the nickel substrate are observed. As the O coverage increases the oxygen peak increases, and there is also a change in the magnitude of the QD and QS peaks of the Ni suggesting that the adsorbing O is changing the arrangement of the surface Ni atoms. Also, the organization of the adsorbed O can be determined by the shift in the QS and QD peaks as the angle of the beam is varied near grazing incidence. As the surface is rotated with respect to the beam, the ions channel along different crystallographic directions of the surface lattice. Each direction will give a dif-

ferent spectrum depending on the orientation of the Ni and O atoms. The grazing incidence experiment also indicates that the initial arrangement of O changes with increasing coverage until there is a reconstruction of the surface Ni atoms. In the discussion following Armour's presentation, the question was raised that perhaps the incident ions were causing the surface reconstruction. Armour did not believe this was so but admitted the question needed further study.

The afternoon session began with a series of presentations on LEED research at York. The session was chaired by Dr. J.D. Pendry (Science Research Council Laboratory, Daresbury) himself an accomplished scientist in LEED research. The York presentations were somewhat of a chauvinistic show presided over by Dr. J.A.D. Matthew (Univ. of York), who posed questions impuning the merit and validity of LEED research which, of course, the York speakers easily dispatched.

In the examination of surfaces using LEED, the crystal structure of the surface, including adsorbed atoms (adatoms) produce diffraction patterns consisting of a number of spots whose symmetry of arrangement is that of a surface lattice. Each spot corresponds to a crystallographic direction of the surface lattice. In the work at York, the intensity of individual spots is observed as the beam voltage is varied. Also, the angle of incidence of the electron beam is varied. A spectrum of spot intensity vs beam energy is obtained which is then compared with a theoretical spectrum based on a specific arrangement of surface atoms.

Prof. M.L. Prutton (Univ. of York) discussed some of the experimental aspects of their LEED studies, in particular the need to control the angle of the beam incidence to 0.1° and maintain the stray magnetic field intensity below 6 mgauss. The data are digitized during collection and must be normalized with respect to beam current. The position of the spot as it moves across the screen with changing angle of incidence must be accurately known.

Dr. J.A. Walker (Univ. of York) discussed the theoretical work. Two LEED computer programs have been developed based on programs published by Pendry in his book *Low Energy Electron Diffraction* (Academic Press, 1978). The one atom/unit cell surface program enables LEED calculations for any crystal face of a one atom/unit cell surface lattice, either for a clean surface or for an overlayer which has a lattice structure that is similar to that of the under surface. A fundamental restriction of this program is that each layer is assumed to be coplanar. Examples of surfaces which can be studied using this program are the Ni [111] and Ni [100] surface with a sodium overlayer. The second program used by the York group is called CAVLEED and was developed by Drs. C.G. Kinniburgh and D.J. Titterington at the Univ. of Cambridge. This program treats the case of two atom/unit cell for either clean surfaces or overlayer systems. In addition to treating coplanar layers, the CAVLEED program is able to treat "rumpled" surfaces in which one group of atoms is displaced out of the surface relative to the other surface atoms.

Dr. M. Martin (Univ. of York) described his studies of the calcium oxide crystal surface. He has been able to fit experimental spot intensity/beam energy curves for the [1,1] lattice direction with the theoretically derived curve.

King (Liverpool) reported on his work with Walker (York) on the LEED analysis of magnesium phosphide crystal surfaces. The atoms in the surface of ionic crystals such as Mg_3P_2 rearrange themselves relative to the bulk crystal lattice so as to reduce surface charge. This surface reconstitution can occur by a lateral shift of atoms or by vertical shifts to form a rumpled surface. King and Walker were able to show from a comparison of experimental and theoretical spot intensity-beam voltage spectra that in the case of Mg_3P_2, surface reconstitution is by parallel shifting of atoms.

Dr. R.G. Jones (Univ. of Cambridge) presented work on the adsorption of the halogens on iron using a combination of surface techniques including Auger spectroscopy, surface potential measurements, LEED and desorption kinetics. The Auger analysis indicated that chlorine adsorbs faster than simple Langmuir kinetics and that although final adsorption is to fixed sites, there is a short-lived mobile precursor state. The surface work function results follow a pattern expected from the electronegativity of the adatoms. The LEED results indicate that with increasing coverage the Cl adsorption

goes through two structural arrangements. Bromine and iodine exhibit three different adsorbed lattices. The second of these structures is a close packed array that then transforms into a square array that resembles the atomic arrangement in the layers of solid Br and I. Desorption experiments indicate a large adsorption activation energy.

Dr. D.P. Woodruff (Univ. of Warwick, Coventry) discussed the potential of surface extended x-ray absorption fine structure (EXAFS) for surface analysis of solids. EXAFS involves the fine structure in x-ray absorption spectra at energies just above principal absorption lines. From the Fourier transform of the fine structure region information is obtained about the position, co-ordination, and polarizing effects of neighboring atoms. Surface EXAFS could be very valuable for obtaining precise information on the position of adatoms and has been used in a study of the adsorption of I on silver [*Phys. Rev. Letters* 41, 309, (1978)]. However, Woodruff pointed out many of the experimental and theoretical problems inherent in surface EXAFS that must be solved before this technique can be effectively used for surface structure analysis.

The final paper was given by Dr. J.C. Campuzano (Univ. of Wisconsin, Milwaukee) on the adsorption of CO on Ni [111] as determined by infrared adsorption spectroscopy. Campuzano observes a stepwise shift in the C-O stretching vibration frequency as the CO coverage is increased. These steps occur at 0.1, 0.2, and 0.25 fractions of a monolayer. The nature of the frequency shifts suggests that there are distinct changes in the adsorption sites and mode of bonding at these steps.

In the discussion that followed the lectures, the point was made that LEED analysis of surface structure has an advantage over other techniques, i.e., PES and ion-scattering, in that in comparing experimental and theoretical LEED spectra, surface (model) structure is an input to the experiment. Within the context of the York meeting, this argument may be true for highly ordered crystal surfaces and adatom lattices. In a more general context in which disordered surfaces and complex adsorbates need to be examined, no single surface analysis method is sufficient in itself. Indeed, the use of as many techniques as possible becomes mandatory as in Jones' study of the adsorption of the halogens on iron. (Willard D. Bascom)

EUROPEAN SMALL-ANGLE NEUTRON SCATTERING—AN UPDATE

Small-angle scattering of light, x-rays, and neutrons are techniques that can be used to study colloidal-like particles ranging in size from ten's to thousand's of Ångstroms. Considerable information can be found out about a number of average properties of such fine particle systems: e.g., size, size distribution, shape, surface characteristics, and internal structure of biological and polymeric substances. The range of research fields utilizing small-angle scattering techniques is vast indeed: biology, physics, chemistry, materials science.

In more recent years, small-angle neutron scattering (SANS) has emerged as a particularly important technique in the realm of "fine particle" science. In fact, SANS has developed principally in Europe. X-rays and optical small-angle scattering have also developed strongly, but SANS is the fair-haired technique of the day. In the not-so-distant future, with the emergence of storage rings (e.g., the National Synchrotron Light Source at Brookhaven National Laboratory), where intensity and collimation will be increased significantly, x-ray small-angle scattering will undoubtedly once again be rediscovered (*ESN* 30-8:367). But for the time being, neutrons are opening doors which were once previously closed for a large number of experiments.

This writer has in the past presented a number of views of the SANS situation in Europe (*ESN* 30-1:36; *ESN* 30-2:73; and ONRL Report 17-75, "Small Angle Scattering at Jülich, FRG"). In the two or so years since those reports were published, SANS has continued to grow in the UK and on the Continent, where a range of new instruments have been built or are being planned. I would like to bring things up-to-date with respect to SANS in Europe.

Before doing so, it would be best to review those properties of neutrons which make SANS such a desirable technique. The neutron, for starters, can

penetrate thick specimens, so that, for example, large metallurgical specimens can be examined. Of further importance, neutrons having wavelengths greater than say 10 Å can be employed, still with good transmission, and can thus be used to avoid double-Bragg scattering from crystalline specimens (see below). Another important aspect of SANS is the possibility of the occurrence of a considerable differential scattering length between two nuclei, when, for the case of x-rays, no intensity might be forthcoming (e.g., Al-Mg alloys).

The SANS prototype, and the leader as well, is in the Institut Laue-Langevin (ILL) at Grenoble, France. ILL remains the *de facto* international center of the field, with workers coming from the world over to carry out SANS experiments at this unique facility. ILL is administered by a tripartite international group comprised of Britain, France, and Germany (the directorship rotating among them). Candidate experiments are submitted by scientists from these countries and are reviewed by the Scientific Committee, who judge the proposal's relative merits. If accepted by the Committee, a specified number of days (e.g., one through four) are allotted, and experimenters receive assistance from resident scientists, who are frequently directly involved with the programs. Nationals outside of the trio do use the D11 small-angle spectrometer, but access under such circumstances is through an interested, sympathetic, resident scientist.

There are complaints that the ILL system is too rushed and that it is most difficult to carry out good, thoughtful science in such a stop-clock environment. Indeed, anyone who has experienced the fatigue of round-the-clock days at ILL will appreciate this view. On the other hand, the facility is highly automated, the computer hardware being such that good experiments can be done quickly—if (!) proper care is taken in experimental design.

The central criteria for state-of-the-art SANS include: (1) a cold source (e.g., liquid H_2/D_2 within the reactor), so that the neutron energy spectrum can be shifted to lower values, i.e., longer wavelengths; (2) area detection, allowing high sensitivity, in addition to enabling the detection of anisotropic scattering. For studies of crystals, if neutron wavelengths can be used which are about twice the Bragg cut-off, doubly-scattered radiation can be avoided, thus eliminating annoying parasitic background in studies of poorly-scattering systems (e.g., defects in crystals). In addition, the reactor must be of adequate power to yield intensities sufficiently great to give meaningful scattering above background. Even a 5-MW reactor is capable of this.

ILL is eminently able to yield optimum scattering conditions. This, together with fine hardware and a highly professional staff, makes the Grenoble facility outstanding. It should be pointed out that a tremendous number of different kinds of experiments are carried out at ILL in biology, polymers, physical chemistry, physics, metallurgy, etc.

There are other extremely active European machines. The reactor facility at KFA, Jülich, FRG, developed and managed by W. Schmatz (currently at Karlsruhe), has been highly productive in solid state physics studies. Much work has been done on defects, magnetism, superconductivity, and phase separation in alloys. The Germans who are associated with the KFA reactor, however, not infrequently take time at ILL owing to the latter's superior intensity and the ability one has to go to lower scattering angles (the D11-SANS spectrometer has a total length of 80 meters!).

In France, at Saclay, the DIDO reactor now has a cold source and an area detector. This facility is engaged mainly in biological and polymer studies. Also in France, at Orsay, a new medium flux reactor is under construction, with an expected completion date of 1980. Several SANS spectrometers are being considered for this reactor, and a cold source is planned as well.

In Italy, there is a SANS facility on the 5-MW CAMEN reactor in Pisa. This reactor, which belongs to the Italian Army, is rented in part by FIAT, who are carrying out nondestructive testing (NDT) using SANS. Specifically P. Pizzi and H. Walther employ a novel SANS spectrometer, balanced by wires and counterweights to adjust for the effects of sinking, Leaning Tower style. Their cold source is liquid propane, and they use an area detector. Pizzi and Walther have been remarkably productive with this less-than-ideal set-up. They have, in fact, pioneered the field of NDT using SANS. It is also rumored that EURATOM's Joint Nuclear

Research Center at Ispra will provide hardware for still another European SANS laboratory. Things are still in the talking stage, but being considered is a spallation unit for the generation of neutrons. Scientists in Germany, by the way, are in pursuit of funds for the construction of a pulsed SANS system, but there are no details yet as to location.

Meanwhile, the UK, though having the availability of ILL, is also building with some apparent vigor. Fully operational, and now spewing out data, is the 5-MW HERALD Reactor at the Atomic Weapons Research Establishment (AWRE), Aldermaston, close to Reading and not far from Harwell. The reactor is in a "sanitized" part of this defense laboratory. The AWRE-SANS spectrometer, fitted out with a H_2/D_2 cold source and a recently installed area detector, is administered by Robin Miller, who, together with Roger Stewart of the Physics Department, University of Reading, is looking at "applied" SANS. Specifically, they are examining creep of Nimonic alloys. A number of groups use the AWRE machine to study polymers and metal alloys. The HERALD SANS facility is a fine, small unit, which is easy to operate and a delight to behold.

Another facility at HERALD, but not directly related to SANS is a Cold Neutron Radiography (CNR) development program, under the guidance of G.S.G. Tuckey, who is doing truly remarkable things with it. The resolution and contrast are exceedingly high, and present new schemes of neutron radiography (as well as a further justification for a cold source!).

In addition the PLUTO Reactor at Harwell now has a 3-m SANS spectrometer and a just recently installed area detector. But, there is no cold source on PLUTO, so the capabilities will be limited.

Perhaps more interesting at Harwell is the construction of a LINAC which should be on-line in early 1979. The machine is being built for the UK's fusion program, but clearly high fluxes of neutrons will be forthcoming. It is planned to develop a position sensitive scintillation detector, with fiber optics leading to photomultipliers. This unit will be designed and constructed at the Rutherford Laboratory, Oxford. It is argued that this machine will prove the usefulness of pulsed neutron beams.

There are currently four SANS units that can be used by UK scientists: at ILL, the D11 and the D17 (a newly constructed SANS spectrometer): PLUTO (Harwell); and HERALD (AWRE). Stewart claims that there is a need for a SANS machine offering a large and variable vector range up to 1 $Å^{-1}$. He also argues for the possibility of separating elastic and inelastic scattering, with good spatial resolution. Stewart states: "An additional factor which must not be overlooked is that the proposed machine...will be in the UK with a flux comparable to D11. This has many advantages for UK scientists; ease of access, no customs problems for samples and equipment, more immediate studies of perishable samples, etc."

Stewart and his co-workers have spent considerable time considering pulsed neutron sources. Care must be taken, he argues, not to design-out flexibility from such a unit. For example, he is concerned with the possibility of designing too small a beam cross section.

All in all, Stewart's arguments for pulsed sources are attractive and demand our future attention.

It is clear that the Europeans have led the world in SANS. Certainly there is much more to be done. In recognition of this, in the US, the National Science Foundation has awarded funds to Oak Ridge National Laboratory to develop a user-oriented SANS resource. This is indeed gratifying, but comes some five years after the ILL-SANS facility was an operational fact. We are, thus, somewhat behind the Europeans. But an added problem is that the Oak Ridge machine will have no cold source, limiting applications, in the main, to noncrystalline systems. This represents a serious shortcoming. American scientists, in need of state-of-the-art SANS, will have to keep traveling to Europe for the forseeable future.

However, there are some recent activities underway, in that Argonne National Laboratory and Los Alamos are considering various accelerator-generated neutrons for SANS. And the National Bureau of Standards has a SANS spectrometer, also without a cold source.

SANS is truly an interdisciplinary experimental technique. Its range of applications to the life sciences, the

physical sciences, and to NDT studies is awesome.

The Europeans have shown us once again, as with automobiles, that small can be beautiful. (H. Herman, Dept. of Materials science and Engineering, State Univ. of new York, Stony Brook, NY)

MICROSTRUCTURAL INSTABILITY IN METALS

One of the most important, and yet relatively neglected criterion in alloy selection for long term service is the mechanical behavior after extended life. Strong alloys are typically supplied in a thermodynamically metastable condition; this means that on an energetic basis they have the tendency to transform their structure to obtain a lower energy condition, but often the kinetics of these natural changes are so slow as to be insignificant. However, under the combined influences of temperature, time, and stress, microstructural changes are often experienced in service, with attendant changes in mechanical properties. Since most alloy specifications are based on relatively short-term tests, this can lead to some unexpected, and often spectacular changes in properties.

In order to address the problem, a one-day discussion meeting was recently (13 December 1978) held by the (UK) Institution of Metallurgists with the title "Microstructural Instability: Its Influence on Long Service Life." As with many of the Institution's meetings, the program was a short designed-schedule of invited talks intended to draw attention to a particular problem area. In this case five papers were presented, outlining the major microstructural changes that occur in various classes of widely used load-bearing alloys, including ferritic and austenitic steels and nickel-based superalloys, and the effect of these changes on mechanical behavior, particularly fracture toughness and creep resistance.

The scene was set with an introductory lecture by Professor J. Nutting (Univ. of Leeds, UK), followed by papers directed toward various classes of alloys, presented by K.R. Williams (Central Electricity Research Laboratories - CERL, Leatherhead, Surrey, UK) on CrMoV steels; B.L. Eyre (Atomic Energy Research Establishment - AERE, Harwell, Oxon, UK) on tramp elements in ferritic steels; P. Marshall (Central Electricity Generating Board - CEGB, Berkeley Nuclear Laboratories, UK) on austenitic stainless steels; and B. Wilshire (University College, Swansea, UK) on nickel-base superalloys.

In his introductory lecture, Nutting ignored instability phenomena that are not important in the majority of structural metals, such as grain growth in pure metals and single phase alloys, and concentrated on phenomena in two-phase alloys such as Ostwald ripening and the influence of superimposed plastic deformation. In practice many two-phase alloys are given what are intended as stabilization heat treatments, such as aging above the service temperature. Nutting pointed out that this does not actually induce thermodynamic equilibrium, that there is still a driving force for transformation at the lower service temperature. This can be appreciated by consideration of the joint effects of time (t) and temperature (T) through a Holloman-type parameter such as is often used in plotting stress-rupture data, i.e., T(A + B log t). In short, Nutting concluded that the idea of "stabilization" is not a sound one at all, since true thermodynamic equilibrium, which is usually characterized by quite weak microstructures, is not actually obtained.

He then turned to a consideration of the form of microstructural changes that lead to property changes, using the example of tempered steels, whose microstructure consists of equiaxed ferrite (nearly pure iron) grains and iron carbide (Fe_3C) particles at grain boundaries. The properties of this material are controlled mostly by the ferrite grain size, with larger grain sizes (R) having lower strength. However, during service at elevated temperature, the carbide particles (r) grow by Ostwald ripening, and through the Smith-Zener relationship (R/r = 3/4f), for a given volume fraction (f) carbides, the ferrite grain size grows also, leading to strength decreases. In this situation one remedy is to get the grain boundaries to break away from the carbide particles so that the particles are within grains, not at the boundaries. This is a much more stable structure and can be obtained by plastically deforming the material and heating.

Another problem is that in some alloy systems, phase changes may be very sluggish, but eventually reactions occur which give undesirable precipitated phases, leading to embrittlement. Two examples of this are σ-phase formation in Fe-Cr alloys and the so-called "475°C embrittlement." The latter effect may take as long as 5-10 years.

Nutting also considered the question of reaction path and phase tranformation kinetics, using as an example the Al-Cu system which is the basis of an important group of heat treatable structural aluminum alloys. In this system a series of different precipitate phases may be formed over a period of time during aging (service) at a given temperature. In the Al-Cu system, the phases and their respective time-temperature tranformation kinetics are well known, allowing appropriate stabilization schemes to be applied. Unfortunately this kind of reaction path information is not known in most alloys, so that much further research is required before microstructural control is possible.

Various other aspects of microstructural instability were touched on by Nutting in his review, one of the most important being the influence of prior plastic deformation; this tends to speed up phase-transformation kinetics. Since many commercial alloys depend on a combination of deformation and precipitation for their high strength properties, this aspect is very relevant to the retention of properties for long times. Also, when two-phase alloys are subjected to thermal cycling and there is a difference in thermal expansion coefficient between phases, this can lead to cracking or dislocation generation and have effects on precipitation reactions and mechanical properties.

The first of the four presentations on specific classes of alloys considered steels of the $\frac{1}{2}$Cr$\frac{1}{2}$Mo$\frac{1}{4}$V type, which are widely used for components operating at high temperature and low stress in, for example, the power generation industry. In his presentation on these materials, Williams took exception to the practice of formulating design stresses for these components based on an extrapolation of short-term property data to 100,000 hours or more (more than ten years). The crux of his argument is that the time-temperature laws on which the extrapolations are based become invalid owing to long-term microstructural changes. Specific microstructural instabilities have been observed in $\frac{1}{2}$Cr$\frac{1}{2}$Mo$\frac{1}{4}$V steam pipe during operation to 100,000 hrs. In particular the gradual formation of Mo_2C carbide particles, grain boundary migration, general VC coarsening, cavitation on grain boundaries, formation of precipitate-free-zones near grain boundaries, and other changes are observed. Williams' approach to this in research at CERL has been to conduct detailed quantitative microstructural studies on samples from components exposed for very long periods of time, with this data then incorporated in a working model for the creep behavior of particle-strengthened ferritic materials. In this way, it becomes possible to predict more realistic design stresses for these high temperature components. This is obviously an ambitious sort of undertaking, applicable only to the most important situations.

Eyre's presentation focused on the influence of "tramp" elements on the low-temperature fracture properties of ferritic steels, with particular reference to their role in intergranular embrittlement, generally called "temper embrittlement." This can cause a marked deterioration in fracture toughness and is known to be associated with the segregation of phosphorus, tin, antimony and arsenic to prior austenitic grain boundaries. These and other tramp elements can also have a deleterious effect on other aspects of the fracture behavior of ferritic steels including their resistance to stress corrosion cracking, hydrogen cracking and reheat cracking in weldments. Clearly all these phenomena can seriously limit the service life of the steels. Eyre discussed recent developments in our understanding of trace element embrittlement, particularly as revealed in recent research at AERE Harwell. Temper embrittlement, being dependent on segregation to grain boundaries, is a time-dependent process. One of the successful approaches to stifle segregation has been to add Mo to the steel composition, which slows down the temper embrittlement kinetics.

Recent AERE work has concentrated on the role of composition. By using NiCr commercial steels as well as "lab" alloys with controlled dopants, particularly tin, studies have been made of the effect, on the ductile to brittle

transition temperature (DBTT), of aging as a function of time at a given temperature. Mechanisms of embrittlement have been pursued with an arsenal of techniques that includes Auger electron spectroscopy of the fracture surfaces to reveal segregation, Mössbauer spectroscopy studies to clarify associations between the dopant element and base alloy constituents (e.g., Sn with Ni), and convergent beam electron diffraction and x-ray analysis to identify precipitated intermetallic compounds (e.g., Ni_3Sn). The first direct evidence of a grain boundary Ni_3Sn compound has been obtained, although this has been speculated on for years as a cause of temper embrittlement. These studies have been conducted for times up to 10,000 hrs (well over a year). As pointed out in the other presentations at this meeting, there is at present no effective way to extrapolate properties over these lengths of time, and certainly it is impossible to predict the microstructural changes that occur over long periods.

On the critical issue of practical solutions to the TE problem, Eyre noted that the simple answer is to reduce tramp element concentration by such means as vacuum melting, but there is a practical limit to the effectiveness of this approach. More clever approaches involve the use of alloying additions, such as Mo mentioned earlier, but the effect of these is not well known at present. Eyre pointed out that the effect of heat treatment schedules needs to be studied further, and the use of more carefully specified operating conditions would help alleviate problems to a great extent.

Another alloy group that typically is put into service in a thermodynamically metastable condition is stainless steels used for components in high-temperature engineering plants. These alloys tend to precipitate carbides and intermetallic compounds throughout the plant lifetime, which can be 30 years or more. Marshall discussed the influence of thermomechanical treatment, service temperature, time, and alloy composition on the development of these complex phases. The consequences of such precipitation depend on the form and quantity of the phases but often there is a degradation of mechanical properties and an increase in scatter. Marshall discussed the implications of these property changes on the design of components for high temperature service, with special reference to very long-term creep, fatigue, and toughness properties of Type 316 stainless steel around 600°C. This is an austenitic steel with about 2-3% Mo added to the common Type 304 composition. One of the serious problems that plagues this alloy is a very substantial variation in properties from one batch of material to another. Furthermore, the cause of these variations involve elements which are not even in the specified alloy composition. Attempts to analyze the materials have led to the determination of numerous precipitated phases that may have deleterious effects, including $M_{23}C_6$ carbide, sigma phase, and chi phase. In fact there are a large number of significant phases found, with various ones favored at different temperatures in the range 600-800°C.

Of particular interest in Marshall's presentation was his consideration of the relative roles of boron, carbon, and nitrogen. Generally speaking, boron has a beneficial effect from the standpoint of microstructural stability, since it tends to delay phase formation. Another beneficial effect is, for example, that the carbide formed when boron is present, $M_{23}(C,B)_6$ keys austenite grain boundaries, preventing grain growth, whereas $M_{23}C_6$ does not. Care must be taken with boron however, since under neutron irradiation conditions in a reactor, nuclear reactions may lead to creep extension of the alloy owing to helium gas formation.

Turning to another problem area, the demand for increasing efficiency of modern aircraft gas turbines has resulted in continuously higher gas inlet temperatures, currently over 1550 K. Even with sophisticated cooling of high-pressure first-stage blades, the normal operating temperature of the superalloy blades may reach 1250 K. In his presentation, Wilshire discussed changes in microstructure that occur under these kind of conditions of prolonged stress/temperature service and their influence on creep and fracture characteristics. Particular reference was made to the behavior of the wrought nickel-base superalloy Nimonic 105 and the cast alloy IN 100. A radically new idea was put forward by Wilshire, involving the use of periodic re-heat treatments to offset the effects of service-induced microstructural changes by restoring the initial microstructure.

This scheme is a practical one since the engines have to be torn down periodically for inspection anyway, and during this period it is convenient to simply subject the blades to re-heat-treatment. Research has shown that by this means, blade lives may be increased by a factor of 2 to 3, which is quite significant on a cost basis for these components. Wilshire discussed the extent to which service-induced changes in the dispersion of strengthening second-phase particles can be wiped out by this scheme.

Another interesting aspect of Wilshire's presentation was a critique he offered of some of the common methods of creep testing. For example, he questioned the validity of variable stress tests on a single sample, where that sample is subjected to a given stress for a period of time, then the stress is increased to a new level. This scheme, which is useful to gather a large amount of creep data from a minimum number of samples, suffers from the obvious deficiency of carrying the creep damage and microstructural changes of the first interval into the next interval, etc. Thus higher values of the stress exponent n in the creep law $\dot{\varepsilon} = A\sigma^n \exp^{-Q/RT}$ are often recorded for multiple tests on the same specimen as compared to a set of single tests on different specimens. Only for microstructurally stable metals will both methods give the same result. Wilshire also discussed attempts to relate time-to-fracture with time-to-tertiary creep in these materials. According to Wilshire, the classical form of the typical creep curve (plot of strain vs time at constant load at a given temperature), which appears as a parabolic curve that turns upward at long times, is attributable to microstructural instability.

The role of boron was also discussed relative to superalloys. In this family of alloys, substitution of carbon by boron tends to eliminate the large, blocky, nonstrengthening MC type carbides, to be replaced by borides. Also a large amount of a γ:γ' entectoid is favored, and the borides tend to tie up elements which would promote formation of the deleterious mu (μ) phase.

A short presentation was also contributed by G.D.W. Smith (Oxford University, UK) who exhibited some spectacular color-mapped field-adsorption microscope images which showed secondary q' structures and elemental distributions between phases in nickel base superalloy 939, together with atom microprobe studies of their composition.

The simple conclusion of the discussion at this meeting is that since most alloys depend on nonequilibrium microstructures for their strength, there is an incompatibility between high strength and microstructural stability in most commercial alloys. However, there are some useful approaches to this apparent dilemma, including schemes to modify and "stabilize" microstructures, slow down the kinetics of transformations toward equilibrium, and schemes to model microstructure/properties changes with time, i.e., to improve the ability to anticipate these changes. Most of this work is in an early stage of development, and considerable further research is required before complete understanding is approached in the many alloy systems which are of interest. (Jeff Perkins)

TAKE A POWDER: EAST AND WEST

Powder metallurgy (P/M) is a modern and competitive materials processing method characterized by minimum material loss, high efficiency, and relatively simple technology; it is particularly suited to the production of complex shapes with uniform structure and properties, i.e., to make products otherwise difficult by conventional metallurgical processing. P/M is a whole new world for the typical physical metallurgist, such as myself, although "powder" metals become relatively normal if they are appropriately consolidated and sintered.

In the true spirit of fostering scientific information transfer, I recently traveled to two P/M conferences held within a three-week period on either side of the (Fe) curtain: 17-19 Oct. 1978 at Gottwaldov, in central Czechoslovakia, the Fifth International Conference on Powder Metallurgy, and 30 Oct.-1 Nov. 1978 at Bowness-on-Windermere in the English lake district, the 1978 Powder Metallurgy Group Meeting. The first of these was the latest in a biennial series of P/M meetings held in Eastern European countries, the last meeting being in Dresden, GDR, in 1977, while the next will be in Bresnanj, Poland, in 1979. The

Bowness meeting was the annual meeting of Activity Group VI (P/M) of The Metals Society (UK). The 1977 meeting was held in Coventry with a theme on automotive and other light industrial applications, while the 1979 meeting will be in London. It might be worth noting that there are several other ongoing "international" series of P/M conferences. For example, the series of European Symposia on Powder Metallurgy (SEPM) are organized every four years by the European Coordinating Committee for P/M (ECC/PM: Scandinavia, Germany, France, Italy, UK); SEMP-5 was in Stockholm in 1978; SEMP-4 in Grenoble. There also is a series in the US held every four years, the last being in Chicago in 1976.

Both these meetings narrowed the P/M field to a specific applications area. In Gottwaldov, hard metal or tool applications were discussed, while in Bowness, the subject was electrical and magnetic applications. For this reason, the two cannot be compared directly, and contrasts between East and West European progress cannot be measured except in the most general sense. Both combined the science and technology of the field. The Gottwaldov Conference had about 300 participants from 12 countries, although there were only about 20 from non-Eastern-bloc countries, and about 20% were from the major P/M research institute in Czechoslovakia, [Vyzkumny Ustav pro Praskovou Metalurgii (VUPM) in Sumperk]. About 60 papers were presented over 3 days, and bound proceedings were distributed. On the other hand, the Bowness meeting does not pretend to be international and was almost entirely a British affair, with only one Eastern bloc delegate; a preprint proceedings volume was distributed. Twenty-four papers were presented in 2½ days.

The program at the Gottwaldov was divided into three parts, which translate as: (1) The Physico-Metallurgical Base of the Mechanical Properties of Sintered Materials; (2) Development of Sintered Tool Materials, Their Properties and their Application to Products with Complex Shape; and (3) Development of Sintered Construction and Other Materials with Low Porosity. The second was the most emphasized.

The Conference began with a series of papers in the first category, on mechanical properties. Academician V.I. Trefilov (Institut Problem Materialovedeniya, Kiev, USSR) led off with a brief review of temperature effects on strength and plasticity of sintered refractory materials, and Conference Chairman M. Slesar [Ústav experimentállurgie, Slovenska Akademia Vied (Slovak Academy of Sciences) (UEM SAV) Kosice, Solovjevova, CSSR] presented an interesting metallographic and microfractographic analysis of strengthening in sintered Fe-P alloys, considering the effect of sintering variables and of the method of phosphorous addition. Also, M. Besterci and E. Dudrova (VEM SAV, Kosice, Solovjevova, CSSR) presented some unique P/M fractography, used in their case for studying the behavior of Cu powder compacts during sintering.

The program section on development of sintered tool materials centered on tungsten carbide (WC)-cobalt (Co) cemented carbide materials. In contrast to many disappointing applications of cermets, Co-bound WC has seen its field constantly expanding since its first application in the 1920s. This material has a unique combination of mechanical properties (high modulus, toughness, wear resistance) that is ideal for tool purposes. Although the use of cemented carbide cutting tools has increased steadily, high speed steel remains the preferred tool material for cutting applications requiring appreciable toughness and resistance to thermal shock, in addition to retention of hardness at elevated temperatures.

Prof. A. Accary (Université de Clermont II, Clermont-Ferrand, France) presented an excellent review on recent trends in hard metal production, particularly WC. The influences of chemical composition and microstructure on mechanical properties were described. Another interesting paper was contributed by K. Nordlund and H. Jonsson (Seco Tools AB, Fagersta, Sweden), who described their efforts to improve the machining properties of WC/Co cemented carbide tools by controlling the structure of the Co-rich (25 w/o) binder alloy by aging and precipitation reactions. Usually WC/Co materials are not used as machine tools when the Co content is greater than about 15 w/o, because of low hardness of the Co binder. Their work included detailed metallurgical studies of the precipitate structures and morphologies. A summary of recent developments in iron-based P/M cutting tools was presented by I. Krasnicka [Statni Vzkumny Ustav Ochrany Materialu

G.V. Akimova (G.A. Akimov's State Research Insitute for Protection of Materials)(SVUM), Prague, CSSR], who included selected results of tool-life tests. He identified various classes of heat treatable P/M tool materials that along with classical tool materials, such as high-speed tool steel and cemented carbides, present a wide spectrum of available materials. These classes include high-speed steel compositions further enhanced by hard particles.

A useful summary of the situation for tool materials was given by Accary who used the classical WC/Co cermet as a reference point, listing several levels of competition from other materials. First, there is the possibility of replacement by another cermet based on a different nonmetallic component and another binder, e.g., Ta (C,N) and TiC/Ni; some "theoretical" guidance is being used here by considering the electronic structure and mechanical properties of the carbides. Another possibility is to replace Co with another binder phase; Ni is most often mentioned but with little success to date. WC may also be replaced only in part by another carbide, notably TaC or TiC; this is current industrial practice which saves rare tungsten and improves engineering products. Finally, quite different materials altogether, such as pure alumina, may replace WC/Co. The future of WC/Co hard metals is expected prominently to involve (1) the development of micrograin materials for machining applications, (2) surface coatings, and (3) alternative production methods of the basic WC powder.

Industrial use of cemented-carbide cutting-tool inserts coated with a thin hard layer via chemical vapor deposition (CVD) is steadily increasing. Several types of coatings, with both single and multiple layers, are available commercially, including TiC, TiC/TiN, Ti(CNO), and TiC/Al_2O_3. Coatings via P/M processes received quite a bit of attention. For example, E. Horvath and A.J. Perry (Berna AG, Olten, Switzerland) discussed the microstructural and surface features of various coating layer structures, relative to wear resistance, and D.M. Karpiner and coworkers (Institute Problem Materialovedeniya, Kiev, USSR) described the formation of plasma coatings from presintered powder mixtures of refractory compounds.

In the section on tool materials and in the third program section on sintered construction materials, quite a few papers were concerned with various special aspects of P/M processing, including isostatic hot pressing, hot extrusion, and rapid induction sintering. R. Schichor and coworkers (UTAR, Bratislava, Czechoslovakia) reported on improvements in properties realized from isostatic hot pressing of P/M high speed steels (HSS) with additions of VC and C+Co to obtain higher proportions of carbide-forming ingredients. The results show tool lives 2-3 times those of conventional HSS and the importance of the hot forming process to obtain this improvement; nonformed P/M tools rate lower than conventional HSS tools. Two British groups reported on the advanced technological development of P/M processing methods. John Dunkley (Davey-Loewy Ltd, Bedford) described a hot extrusion process for the production of P/M parts from conventional highspeed compositions. Also, a university-industry team (University of Bradford and Edgar Allen Tools Ltd, Sheffield, UK) reported on their particular method of producing sintered-to-shape high-speed tool steel components; the process reputedly leads to tools that perform as well as conventional wrought high strength steel tools. From the theoretical viewpoint, V.M. Gorochov and coworkers (USSR) outlined an interesting analysis of hot pressing processes in which equations were developed that express changes in density of the material as a function of pressing time, pressure, and plasticity of powder. It was shown that the popular isostatic pressing conditions are not necessarily optimum for all materials.

Other interesting papers on P/M processing included a presentation by A. Cyunczyk [Polytechnika Rzeszowska im Ignacego Lukasiewicza (Technical University), Rzeszow, Poland)] on laboratory investigations into vibratory hot pressing (VHP) of aluminum flake, which is useful to overcome the influences of surface oxidation. Moreover, formation of fine grained structure is reportedly favored by VHP. I.I. Ivanova and coworkers (Institut Problem Materialovedeniya, Kiev, USSR) discussed the structure of dispersion strengthened steel as formed during processing by various methods. Interaction of the TiO_2 strengthening phase with components

of the sintered steel matrix was studied with particular interest in elevated temperature stability. And in a presentation connected to the Bowness Conference theme, J. Doruska and J. Miklik (PRAMET, Sumperk, CSSR) reported on laboratory experiments for isostatic hot-repressing of Mn-Zn and Ni-Zn ferrites for magnetic core applications.

Contributions from both Germanies related to the use of rapid induction sintering, a process that may have problems due to (1) insufficient time available for degassing the powder compact, and (2) differential heating from surface to interior. However, this latter feature could also possibly be used to advantage in various ways. G. Leitner and W. Hermal (Zentralinstitut für Festkorperphysik und Werkstoffforschung AdW, Dresden, GDR) outlined the situations in which the rapid inductive heating technique is applicable for sintering P/M parts. Materials' properties, geometry, field invasion behavior, etc., were considered. Also, V. Gemenetzis and coworkers (Universität Karlsruhe, FRG) reported on their work on this method.

Turning to highlights of the Bowness meeting, the program was started by D.H. Jones (GEC Hirst Research Centre, Wembley, UK) who reviewed the application of tungsten, molybdenum, and other alloys in the electric lighting industry, with reference to the properties required of the various materials. For example, for general lighting service and halogen lamps, it is essential that the tungsten filament remain sustantially free of movement and be capable of withstanding shock and vibration. These features are achieved by close control of the metallurgical microstructure developed during the recrystallization process. Pure undoped tungsten is unsatisfactory because it r crystallizes at a relatively low temperature to give an equiaxed grain structure that grows during filament operation, leading to a high rate of "sag" via grain boundary sliding. The approach to this problem is to begin with a stable microstructure through the combined effects of additions of small quantities of refractory oxides and alkali metal compounds together with controlled amounts of cold work. It is the requirement for this mixture of constituents which has historically depended on P/M techniques. Jones' presentation was essentially a report on facts-of-life in the industry, supported by some interesting microstructural data.

D. Hadfield (Swift Levick and Sons Ltd., Sheffield, UK) presented a similarly oriented review on P/M magnet materials. It is rare that when reviewing the development of a particular technology one is able to start over two centuries ago. However, this is the case; bonded powder magnets have been known since the mid-1700s. Indeed, the original naturally-occurring permanent magnet, the Lodestone, c. 3000 B.C., consisted of compounded oxides, namely ferrous ferrite [FeO, Fe_2O_3] with a BH energy product of about 1 kJ/m^3. Contemporary sintered rare-earth cobalt magnets now achieve energy products 250 times this value. In fact, Hadfield showed that a plot of log energy product vs. time is linear. He also made the interesting observation that the average (British) home has on the order of 50-100 magnets, i.e., we have become <u>very</u> dependent on them, as they are central to the design of synchronous motors in clocks and timers, relays, switches, meters, etc. Hadfield discussed the processing requirements and microstructural features of contemporary magnet materials such as sintered Al-Ni-Co-Fe magnet alloys, micromagnetic materials (Fe and Fe_2Co), ferrite ceramics (e.g., $BaO{\cdot}6Fe_2O_3$), and rare-earth cobalt (e.g., $SmCo_5$).

This "affluent society" theme was echoed by C.D. DesForges (Engelhard Industries Ltd., Chessington, UK), who reviewed the requirements of P/M materials for electrical contacts. There are numerous developments in electrical technology that would be impossible without reliable contacts, and when the requirements are examined carefully, it is quickly evident that materials' features are controlling. The primary requirements for contacts are clean flat surfaces. Unfortunately we don't have a very full understanding of the relation between the microstructure of contact materials and their properties (for example erosion wear resistance). While this knowledge may not be essential for immediate technological progress, it will be invaluable in the future and is of basic scientific interest.

As in Gottwaldov, several of these review papers were careful to make observations on the materials' technologies that compete with P/M for various applications. For example, certain mag-

netic core materials, currently produced mainly by P/M, could revert to melting and casting in the future, depending on the trend of properties, cost, and requirements. For contacts, various deposition techniques compete with P/M, and there is also the possibility of eliminating switching devices altogether with new science (solid state switches).

In another review presentation, B.G. Street (Mullard Magnetic Components, Southport, UK) outlined the principles of production technology for permanent magnet ceramic components (hard ferrites) and ceramic transformer/inductor cores (soft ferrites). Also, B. Weglinski (Wroclaw Tech. Univ., Poland) discussed P/M composites for magnetic cores, and the properties of sintered alloys and press-molded metal powder/resin compacts were considered. Special attention was given to the dependence of magnetic induction on the density of sintered alloys presented in the form of "lines of standard induction," useful in estimating the magnetic effectiveness of manufacturing processing. B.A. James and G. Williams (GKN Group Technological Centre, Wolverhampton, UK) presented a review of the magnetic properties of sintered iron materials (Fe, Fe-Si, and Fe-Ni), considering the effects of variations in sintering conditions, initial particle size, and material purity. Also considered was Fe-P, a recently introduced family of materials with extremely promising magnetic properties.

In the area of electronics, G.L. Davis (Mullard, Mitcham, Surrey, UK) reviewed some miscellaneous applications of P/M in the electronics industry, while D.J. Anderton (Johnson Matthey Research Centre, Reading, UK) and F.R. Sale (Univ. of Manchester, England) presented two joint papers on the production of conducting oxide powders, one involving the preparation of lanthanum cobaltite ($LaCoO_3$) by a freeze-drying technique, the other a so-called amorphous citrate process; these are substitutes for the usual commercial process involving repeated sintering and melting of a carbonate/oxides mixture. Also several papers were given relating to conductors, i.e., copper-based materials. One of the most interesting topics here was considered by E.P. Weber and A.V. Nadkarni (Glidden Metals, Cleveland, OH), who discussed P/M dispersion-strengthened copper, a potential electrical engineering material with interesting new properties such as stability at high temperatures.

In addition to the bulk of papers on the main Conference theme, several papers related to P/M structural materials, particularly steels, and processing methods, and in this sense, related directly to the theme of the Gottwaldov Conference. **J.A. Pardoe** [UK Atomic Energy Authority (UKAEA) Springfields Laboratories, Preston, UK] discussed the so-called "Conform" continuous extrusion process invented by the UKAEA. In this, material is fed into a peripheral groove in a rotating wheel, advanced by friction into a space between the groove and tooling supported by a fixed shoe, and then extruded through a die. Among the particulate metals investigated have been aluminum and copper, naturally of interest to the electrical industry. Higher strengths can be obtained, often without a decrease in conductivity, and are attributable to an oxide dispersion hardening effect. L.E. Svensson and U. Engstrom (Hoganas AB, Sweden) discussed improvements in the precision of sintered components made from partially pre-alloyed steel powders. Improvement of dimensional tolerances by using a copper-iron alloy powder instead of an elemental mix was explained by the fact that segregation of constituents is minimized and a more uniform microstructure is obtained. Also, N. Dautzenberg (DEMAG-Meer, FRG) discussed surface treatment of sintered steels by borification.

Naturally the classical question arises: How do the Eastern European countries seem to compare with us on the basis of science and technology? In the case of powder metallurgy, where my insight into the field can be etched on the side of one powder particle, I cannot give an answer; but I don't think the answer would have been evident to anyone from these two meetings. Neither went particularly far in presenting fundamentals of powder metallurgy behavior, although Gottwaldov probably tried harder than Bowness. Paradoxically, there also seems to be a need for more specific purpose-oriented work. A problem with both meetings was one of conflicting data and too many isolated pieces of research that are not cross-comparable with each other; this is particularly true in the P/M tool area, in which each project seems to be small and specific.

What appears to be needed are reports on farreaching projects or cooperative efforts to sort out the basic controlling factors for the properties of P/M materials. (Jeff Perkins)

MECHANICS

"PREDICTION" METHODS FOR TURBULENT FLOWS

In differentiating between fluid mechanics and hydraulics, Theodore von Karman once defined hydraulics as the science of variable constants. Because hydraulics was an engineering discipline that concerned itself with the design of pipe lines, measuring nozzles, wiers, dams, and other hydraulic equipment at a time when the fundamentals of fluid mechanics were little understood, it was necessary to incorporate empirical data into a design procedure that would result in successful prototype equipment. All the factors of ignorance were combined into coefficients which, it was hoped, did not vary strongly over a wide range of design conditions. However, it was soon noticed, for instance, that friction factors for pipes varied somewhat with flow Reynolds numbers, pipe roughness and fouling, and that discharge coefficients of nozzles varied with detail nozzle design and flow Reynolds number. It was in the hope of relieving some of the uncertainties in the empirical treatment of turbulent flow that von Karman and G.I. Taylor set about, during the thirties, to provide a rational and fundamental analysis of turbulence phenomena in fluid flow. The simplest problem that could be formulated was that pertaining to an average flow field in an incompressible fluid, which resulted in homogeneous turbulence. The problem was then further restricted so that the properties of the turbulence being studied were isotropic. The study of homogeneous, isotropic turbulence has since occupied the thoughts of many of our great mathematicians and physicists until at the present time progress in this area has almost come to a standstill. While turbulence was being studied analytically, the development of the hot-wire probe in the late thirties and early forties made possible the experimental study of turbulence; many of our experimentalists in hydrodynamics were thereafter engaged in exploring the properties of turbulence produced behind screens in low turbulence wind tunnels.

It was unfortunate that neither the fundamental theoretical nor the experimental studies related to any situation of engineering importance, and so the turbulence community finally gravitated toward the approximate modeling of real turbulent flows. The present state of such modeling was presented at the von Karman Institute for Fluid Dynamics (Rhode-Saint-Genèse, Belgium) from 15-19 January in a lecture series entitled "Prediction Methods for Turbulent Flows."

Prof. John L. Lumley (Cornell Univ., Ithaca, NY) opened the series with a lecture entitled "Second Order Modeling of Turbulent Flows." In this lecture the theory of second order modeling was presented in detail, and Lumley presented his evaluation of the various approximations and areas of ignorance involved. The basic approach considered the averaged momentum and energy equations, identified the various terms such as convective transport, diffusive transport, production by bouyancy, production by shear, and viscous dissipation and modeled these turbulent transport terms in terms of turbulent transport coefficients and gradients of average quantities. The coefficients were then evaluated from experiments that related to the flows being modeled. The modeling of higher order transport of scalar fluxes was also illustrated by Dr. W. Rodi (Univ. of Karlsruhe, FRG) who later illustrated this modeling in applications to environmental fluid mechanical problems.

In contradistinction to the modeling of turbulence via various approximations to the averaged Navier-Stokes equations and equations of higher order, the direct numerical simulation of turbulence attempts to integrate the Navier-Stokes equations directly without any further approximation. Dr. U. Schumann (Kernforschungszentrum, Karlsruhe, FRG) presented a lecture on such simulation and the difficulties encountered. Even for the case of a two-dimensional average flow, it is necessary to integrate the Navier-Stokes equations in three spatial dimensions and time because turbulence occurs in all of these dimensions. This means that for practical application, one selects a limited region of the space-time being studied

and divides this into a four-dimensional grid. At low Reynolds numbers, a computationally feasible space-time grid can resolve the turbulence, but at high Reynolds numbers it is impossible to have a grid with sufficiently fine spacing to resolve the smallest details of the turbulent flow and at the same time allow computation in a reasonable time. Therefore, for high Reynolds numbers simulations, the small scale structure of the turbulence is again modeled in a manner based on the cascade process of Kolmogoroff. Besides this weakness in the direct numerical high Reynolds numbers flows, another weakness can be illustrated by considering the problem of Poiseuille flow between parallel walls; in modeling this flow a segment of the flow field that is a rectangular parallelopiped with two faces that are coincident with the bounding walls and two other sets of faces that are parallel and perpendicular to the average flow direction, respectively, is chosen with flow boundary conditions that are repeated at the extremes of the segment. The tacit assumption made is that the turbulent flow field is periodic in detail with streamwise and cross-streamwise periodicities given by the dimensions of the segment. If the cause of the turbulence is a basic instability in the flow field, the choice of segment scale fixes the streamwise and cross-streamwise disturbance wave numbers (and line spectra), so it is necessary to study a range of segment scales to determine their effect on the calculated turbulent transport. Schumann discussed two methods of integrating the Navier-Stokes equations. One used finite differences and the other spectral methods. Spectral methods using trigometric functions and Chebychev polynominals in connection with fast Fourier transform methods have been under development by Prof. Stephen Orzag and coworkers at MIT.

Methods of modeling turbulent flows in physical and spectral spaces were presented by Prof. J. Mathieu (Ecole Centrale de Lyon, France). Mathieu raised the situation in which a large amount of turbulent energy is introduced in a very small area of the spectrum. The usual modeling in physical space that does not differentiate between different energy spectra of the turbulence in the flow would obviously not work here. Mathieu also discussed the desirability of evolving a spectral method that takes into account the interaction of turbulence and coherent structures of various scales.

The application of turbulence models to geophysical flows was presented by Prof. J.C.J. Nihoul (Univ. de Liège, Belgium). In the ocean, turbulence appears basically in two thin layers. First, there is an upper mixing layer of thickness of 100 m filled with turbulence generated by the breaking of surface waves caused by interaction with atmospheric factors. Secondly, there is also a turbulent bottom layer with a thickness of approximately 10 m, somewhat similar to the atmospheric boundary layer. The internal layer that fills the rest of the thickness of the ocean has only intermittent turbulence appearing in the form of isolated patches. This intermittent turbulence may be caused by internal waves that reduce the local Richardson number and cause Kelvin-Helmholtz instabilities. Nihoul then presented results of modeling the turbulence in the North Sea.

In a pair of related lectures Dr. W.P. Jones (Imperial College of Science & Technology, London, UK) and Dr. R. Borghi (Office National d'Etudes et de Recherches Aérospatiales, France) discussed prediction models for turbulent flows with variable density and combustion. For this case the governing equations are the momentum, continuity, chemical species, and enthalpy conservation equations. It is fortunate that reactions associated with the high temperature oxidization of hydrocarbon fuels usually have time scales that are very short compared to the times characteristic of the transport processes. Under these circumstances the assumption of chemical equilibrium of the products of combustion provides a reasonable approximation.

The last lecture of the series entitled "On the marginal instability of a class of turbulent flows" was presented by M. Lessen (Univ. of Rochester and ONR London). The mechanism of pumping the turbulence in the flow field through a neutrally stable, normal mode disturbance of the average field was discussed in terms of its being a physical characterization of the production term in the closure models. In counterdistinction to the closure models, no parameters need be evaluated in order to predict the average properties in transport when using the marginal instability principle. Examples involving traveling wave dis-

turbances in jets, wakes, mixing layers, and convective disturbances in turbulent Taylor-Couette flow were cited.

The fact that the closure schemes involve parameters individually evaluated from relevant experimental data of the various classes of flow considered might indicate that the field has not progressed far from the point of von Karman's original characterization of hydraulics; there has been progress, however, in recognizing some of the difficulties involved. For additional progress, researchers must free themselves from the procrustean bed of the classical formulation of turbulence and endeavor to supply more physical insight into at least the production process which, I feel, involves an instability. I found the meeting stimulating and thought-provoking.
(Martin Lessen)

MEDICAL SCIENCES

SOME EUROPEAN RESEARCH IN PARISITOLOGY

In a very short tour as a Liaison Technologist with ONRL, visits were made to several centers of parasitological research in Europe. This article discusses three of these laboratories.

The Hospital of Tropical Disease, St. Pancras Hospital, London, has two wards of thirty beds each; the Chamberlain Ward is supervised by Prof. A.W. Woodruff and Dr. H.A.K. Rowland and the Manson Ward by Dr. Anthony Bryceson and Dr. Anthony Hall. Patients include expatriots from the tropics living in Britain, British people living in or having recently visited the tropics, tourists from the tropics visiting the UK, and patients referred from tropical countries. Doctors in the hospital are members of the Department of Clinical Tropical Medicine at the London School of Hygiene and Tropical Medicine (LSHTM), where they teach clinical tropical medicine to the students, as well as to the medical and nursing students and house staff of the University College Hospital, Univ. of London. Occasionally, they also give consultant service to other hospitals and medical schools in the London area regarding tropical infectious diseases and other problems. The St. Pancras facility is considered the best English-speaking one at which to learn tropical medicine outside of the tropics, but the research opportunities of the St. Pancras staff are limited by their heavy teaching and clinical responsibilities. However, they advise about 12 to 15 students in the Master of Science program in Clinical Tropical Medicine at the LSHTM in their thesis research. They also have a few students in a PhD program.

A member of Woodruff's staff is Dr. Stephen Wright, who for several years has been interested in the pathophysiology and pathogenesis of giardiasis. Giardiasis is caused by an intestinal infection with the protozoan parasite, *Giardia lamblia*. It is a common cause of malabsorption, diarrhea, weight loss, and general abdominal discomfort in individuals in both the tropical and temperate climates. It has been frequently reported to cause illnesses in visitors to Leningrad and to ski resorts in the US. Wright has performed extensive clinical studies of patients with *Giardia lamblia* infections and is currently attempting to culture small intestinal biopsies to study the local immune response of the intestinal mucosa. His reports have helped to describe the clinical characteristics of this disease that until recently was believed not to be pathogenic to man.

The Catholic University, Nijmegen, is the site of much of the malaria research in the Netherlands. The research is performed in two units; the Department of Medical Parasitology, under the leadership of Dr. T.H.E. Meuwissen, and the Department of Cytohistology led by Prof. CHR Jerusalem. In the Department of Medical Parasitology a wide range of research is being performed. Meuwissen himself is involved in culturing *Plasmodium falciparium*, the malaria species most dangerous to man. The technique is to collect malaria parasites from the blood of infected patients and culture them with media and human red cells. This is probably the only laboratory in Europe, exclusive of Britain, culturing malaria parasites. Meuwissen and his colleagues can culture the parasites for prolonged periods and have been able to obtain large numbers of the stage of the parasite that is infectious to mosquitoes, the gametocyte. So far, these gametocytes have not been infectious to mosquitoes, and thus the group has not been able to complete

the life cycle of the parasite, one of the major goals. Nevertheless, they have recently successfully fed mosquitoes on infected blood through a membrane. Each of these steps is important in the development of a malaria vaccine. Earlier studies in this laboratory used infections in monkeys, but with the success of their culture technique they are now able to limit their studies to blood from infected people and rodents, cultures and mosquitoes. A side project is that each malaria parasite isolated from humans (ten as of this time) is tested *in vitro* for drug (chloroquin) sensitivity.

Dr. J.P. Verhave, an associate of Meuwissen's, is studying the stage of the parasite between the stage in the mosquito (sporozoites) and that in mammalian red blood cells. Verhave is attempting to culture these exo-erythrocytic (liver) forms. He has found that it is impossible to immunize an animal and obtain protective immunity with irradiation attenuated sporozites while the animal has a red cell infection. This is pertinent to the application of a malarial vaccine since many individuals needing immunization would have malarial infections at the time.

Among other research, Rob Bos, a graduate student at the University, is studying the pathophysiology and immunological aspects of the hemolytic anemia associated with malaria infections, while Dr. Van Druten is working on mathematical models for malarial transmission. Van Druten uses serological data obtained from other studies and with complicated mathematical formulas calculates malarial transmission rates. Dr. P.A. Beckers, also of the Medical Parasitology Department, is working on the parasitic disease, Pneymocystosis. Besides working with an infected rodent model and attempting to culture the organism, he is purifying parasitic antigen in order to produce antibody for detecting antigen in the sputum and sera from suspected human cases. Pneymocystosis is an increasing problem in developed, as well as, underdeveloped countries. Not infrequently, individuals with a malignancy and receiving therapy develop a severe pneumonia due to *Pneumocystis carinii*. There are drugs that can cure the infection, but often it is difficult to make the diagnosis. If Beckers can develop a good test for detecting the infectious agent in sputum or sera, the clinical care of these patients will be significantly improved.

In the Cytohistology Department extensive research is being performed on the immunopathology of malaria. One individual working with Jerusalem is Dr. Lambert Poels, who has detected malaria antigens on the surface of infected red cells but not on uninfected red cells. He has also shown that infected reticulocytes (the younger stages of red blood cells) are capable of producing immunity when injected into animals. In other studies looking for autoantibodies in animals infected with malaria, he has detected antibodies to smooth muscle, antinuclear factors in animals cured of malaria, and immune complexes in the kidneys of rodents infected and cured with malaria many months before.

The Parasitology Department of the National Bacteriological Laboratory, Stockholm, Sweden is located in two places; at the main National Bacteriological Laboratory and at the Roslatstulls Sjukhus, the Infectious Disease and Tropical Medicine Hospital of the University of Stockholm. The laboratory directed by Dr. Gunner Huldt has six to eight doctoral level investigators and a large number of laboratory technicians,and they perform the serological tests for parasitological diseases for the entire country. They are also the reference laboratory for parasitological stool and blood smear examinations and make reagents for diagnostic tests. Dr. Robert Berkquist, Deputy Director of the Laboratory, is responsible for production of reagents, including labelled antibodies. A research program is starting on the production and characterization of diagnostic antigens for schistosomiasis.

The research performed under Huldt's direction covers several areas including: (1) the production of antigens for studies and diagnostic techniques for *Schistosomia mansoni* infections; (2) study of enteropathogenic protozoa as part of a larger study of diarrheal diseases; (3) immune modulation in trichinosis (This is being performed by Dr. Inger Ljunstrom.); (4) application of the use of enzyme labelled antibodies; (5) studies of secretory IgA antibodies in *Amoebae* and *Giardia* infections. Huldt has studied *Toxoplasma gondii* in the past.

A very interesting project uses the new TIA diagnostic technique. This is a thin layer immunoassay using plastic surfaces. The technique consists of applying a liquid containing a solu-

ble parasitic antigen to a plastic petri dish. Some of the antigen is absorbed to the dish, while the excess is then poured off. Drops of test sera from patients with the suspected disease are then placed over the antigen. After a period of time this is washed off. An antihuman globin is then applied which increases the resulting antigen antibody reaction. Following the application of moisture, which can simply be breathing over the dish, a positive reaction will give a clear area over the precipitation of the antigen and antibody. This simple test is applicable to direct field work in the Tropics. It can be used for either qualitative or quantitative detection of antibodies.

The Tropical Medicine Ward at the Roslagstulls Sjukhus has 20 beds where patients with tropical diseases are treated. The patients include Swedes who have visited the Tropics as well as people from tropical countries. Clinical training in tropical medicine is performed on the Ward, and all Swedish specialists in infectious diseases have to take at least one week of training here. There is a collaborative arrangement to study malaria in Liberia. I saw several interesting cases during my visit, including patients with schistosomiasis, onchocerciasis, paratyphoid fever, and fevers of undiagnosed origin. Also admitted are patients from tropical areas with non-tropical infectious diseases. (CAPT G.T. Strickland, MC, USN, Liaison Technologist from the Department of Medicine, Uniformed Service University of the Health Sciences, Bethesda, MD)

PHYSICAL SCIENCES

THE VANISHING DAGGER AND OTHER HOLOGRAPHIC MIRACLES

On 6 December 1978, at the IEE Building in London among a number of interesting items on exhibit, we found an absolutely lethal-looking dagger, pointing straight up. When we tried to touch it, it vanished. Another item, a most beautiful golden apple, was seen sitting in mid-air. Again, whatever part of it we touched disappeared. Illusions? Yes, in a way. Actually, just very-well-done real-image holograms from the laboratory of N.J. Phillips of the Univ. of Loughborough.

These and several other holograms were exhibits that accompanied a one-day colloquium held at the headquarters of the Institution of Electrical Engineers. The IEE conducts a regular series of such colloquia, symposia, and lectures on topics of current interest. This one had the title "Holographic Displays," was "intended to be of generally informative nature rather than to include discussions of great technical depth," and was attended by well over 100 people. The participants appeared to be a good mix of engineers, professors and students, persons with product-marketing interests, and individuals engaged in the creative arts. The nine lectures covered white-light and volume holography, holographic recording on photographic and thermoplastic films, laser and light source requirements, applications in Engineering and the Arts, information storage, and head-up displays.

Since holography has been a well-established technique for a number of years we shall review the basic idea only very briefly. Readers interested in more details are referred to two introductory articles in *Scientific American* (E.N. Leith and J. Upatnieks, June, 1965; E.N. Leith, October 1976) or to the many technical articles and several textbooks available on the subject.

An ordinary photograph is a record of the distribution of the intensity of the light reflected from an illuminated subject and focused by a lens onto a photographic film. Phase information of the electromagnetic waves constituting the light that arrives at the various portions of the film is lost.

In holography, on the other hand, the recording takes the phase of the wave that strikes the film surface into account by adding the light from the subject to that from an optical reference beam of known phase. When the array of recorded microscopic dots of varying intensity that correspond to the pattern of the light from the subject, mixed with that from the reference beam, is illuminated with a laser in the proper manner, the resulting Huygens-source construction can produce what the eye can perceive as two images. One of these, the virtual image, gives the viewer the impression that the subject

is being seen as through a window. The advantage of this method of viewing a photographic reproduction is that the three-dimensional aspect of the subject is preserved. Also, suppose a portion of the subject is not seen when viewing it straight on because an obstacle is in the way. In real life, by moving slightly to the side, the previously hidden area becomes visible. The same is true for the virtual-image hologram.

The other image, the real-image hologram, is even more exciting, for it gives the viewer the impression that the actual subject is not just being viewed through a window but that it actually appears in front of him in three-dimensional form as a real object.

It was real-image holograms of the dagger and of the apple that we saw, and they were so realistic that they indeed looked real.

Clearly, such effects of true three-dimensional reproduction can be expected to lead to a number of commercial products. If we note that the development of commercial inexpensive color film has virtually supplanted black-and-white photography, we can easily forecast how the market would shift if true three-dimensional photography (i.e., holography) came to be available commercially at a reasonable price.

Since holography of three-dimensional objects has been a reality for more than a dozen years, then why has development on a commercial scale not yet materialized?

Probably one reason has been the need for lasers for making the holograms and for viewing them. If some good and cheap way of making and viewing holograms with white light of reasonable intensity could be developed, a new commercial product would result.

As it has turned out, processes for using white light for both recording and viewing holograms have indeed been devised. While the recording technique is somewhat involved, so that the use of lasers might remain preferable for a while, white light viewing, at least in subdued room lighting, is certainly a reality. The dagger and apple that we referred to earlier were viewed under directed white light.

It was white light holography that was the subject of the introductory talk of N.J. Phillips. He briefly described the technique invented by S. Benton (Polaroid Corp.) for creating a bright, stereoscopic virtual-image hologram that has horizontal (but not vertical) parallax and is viewable in white light. He suggested that present development work in the US is related to that technique and, in addition, has the aim of image recording with white light.

Considerably more time was spent in discussing the work in progress in the Soviet Union. It was there, in 1962, that Yu N. Denisyuk (a Lenin-prize winner associated with NIKFI, Moscow, and the Ioffe Institute, Leningrad) made a major advance by combining holography with the form of color photography invented by G. Lippman in 1891.

In the Denisyuk technique, which is illustrated in Fig. 1, the image is recorded as a volume hologram in a photographic film whose thickness corresponds to a number of wavelengths of light. Interference between the

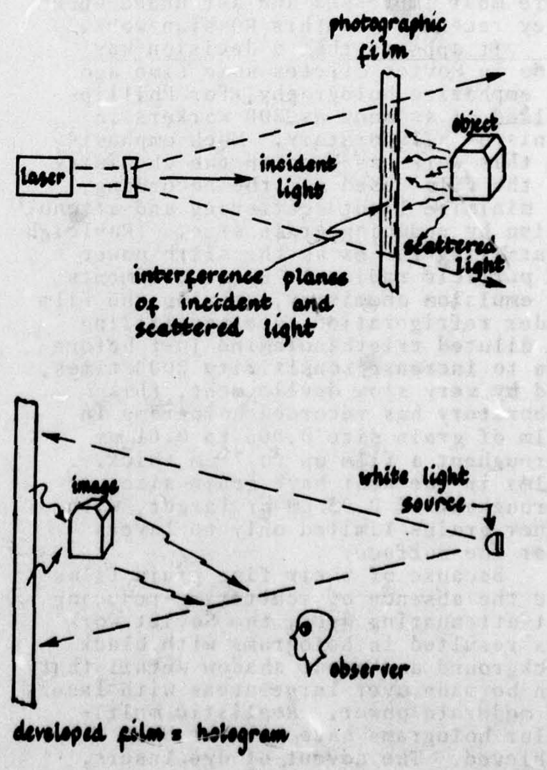


Fig. 1.

laser-produced reference beam, which here is also the incident beam, and the light scattered by the object forms a layered interference pattern in the film. When the developed film is illuminated with white light in the manner shown in the bottom of the figure, a real image results. If the film has not changed dimensions during development, the image will have the color of the laser used for recording. In principle, if recording is carried out with laser light of the three primary colors, a hologram of the quality of color TV should result.

The dagger and apple mentioned earlier were Denisyuk-type single color reflection holograms.

While they appeared beautiful to us, Phillips stated that they were of much poorer quality than Russian-produced holograms that he had seen and that, in fact, his American colleagues were most impressed and astounded when they recently saw this Russian work.

It appears that a decision was made in Soviet circles some time ago to emphasize holography, for Phillips talked of as many as 200 workers in Denisyuk's laboratory. Much emphasis in this work has been on the chemistry of the films used for the recording, to minimize light scattering and attenuation by reducing grain size. (Rayleigh scattering varies as the sixth power of particle radius.) By developments in emulsion chemistry, storing the film under refrigeration, pre-sensitizing in diluted triethanolamine just before use to increase sensitivity 2000 times, and by very slow development, this laboratory has recorded holograms in film of grain size 0.005 to 0.01 μm throughout a film up to 7-μm thick. Films in the West have grain size throughout of 0.03 μm or larger, with finer grains limited only to layers near the surface.

Because of their fine grain films and the absence of scattering-reducing but attenuating dyes, the Soviet work has resulted in holograms with black background and great shadow detail that can be made over large areas with lasers of moderate power. Realistic multicolor holograms have not yet been achieved. The advent of dye lasers, perhaps with recording in six different colors, is expected to solve this problem.

In the second talk, M.C. Adamson (JK Lasers Ltd., Rugby, UK), who summarized requirements of lasers, emphasized the desirability of single-mode operation to permit holographic recording with a large depth of field.

Since white-light viewing of reflection holograms is now an accepted fact, E.J.G. Beeson (Thorn Lighting Ltd., Leicester) summarized the capabilities of present projection lamps. A good rule of thumb here is that a 150-W projection lamp is sufficient to light a good hologram 1 m × 1 m in area.

Representing Agfa-Gevaert Ltd., D.W.P. Croucher, the London-based Scientific Product Specialist for the Antwerp-based firm, discussed such basic topics relating to emulsions as contrast, spectral sensitivity, and film speed. ("Speed is proportional to grain size and therefore inversely proportional to the resolving power of the developed image.") He suggested that Phillips's was denigrating his own work. (And we agree!) He also stated that Afga-Gevaert was close to producing films commercially of half the grain size presently available.

Although chemical means, such as silver halide film, are most common for holographic recording, there are other techniques. Specifications of a commercially available device that records on a thermoplastic medium, similar to the technique first reported by Urbach and Meier in 1966, were discussed by R. Carless (Lamda Photometrics Ltd., a sales organization in Harpenden, Herts., UK). The apparatus, which is manufactured in Germany by Rottenkolber Holo-System, uses thermoplastic 35 mm film developed by Kalle-Hoechst (FRG) of resolution 1500 lines per mm, a sensitivity of 50 ergs/cm^2, and a diffraction efficiency of 30%. Since the total time required for sensitizing with an electric charge, exposing, fixing, and moving the film is only 40 sec per frame, the apparatus is said to be of great utility for engineering or industrial applications where repeated rapid holographic recording is required. According to Carless, this apparatus is distributed in the US by Apollo Lasers, Los Angeles.

Mr. A. Furst (Holoco Ltd., Shepperton Studio Centre, Middlesex, UK), who is involved in set and action design for the film and TV industry, speculated briefly about the substitution of holograms for real, full-size scenery. He was followed by J.M. Webster [Central Electricity Generating Board (CEGB), Marchwood, UK)], who discussed some engineering uses of holography.

Webster pointed out that since the basic Rayleigh criterion for optical resolution applies to holograms, i.e., the minimum resolved spot-size varies inversely as aperture dimension, a hologram of large area is capable of much finer resolution than an image recorded through a lens. In addition, for best presentation of details the examination of a picture taken with high resolution photographic film located at the plane of a pseudoscopic real holographic image is superior to the viewing of a virtual image with a magnifying telescope because the effective aperture of the hologram is larger and the speckle effect is diminished.

Examples of holograms made at CEGB were on exhibit. Recordings of this type are especially useful to a power company for providing highly accurate three-dimensional information of large structures against which future deformations or movements might be measured, for providing prior familiarization to repair teams who are permitted to be in a hostile environment, such as a nuclear reactor, for only brief periods, and for similar applications.

Optical memories have been under development for a number of years (cf. J.P. Huignard, F. Micheron, and E. Spitz, "Optical Systems and Photosensitive Materials for Information Storage," in *Optical Properties of Solids New Developments*, B.O. Seraphin, Ed., North-Holland Pub. Co., 1976). B.D. Rogers reported the ongoing development of such a two-dimensional memory of up to 10^{11} bits capacity with MHz data rate in his organization, Plessey Research (Caswell) Ltd. UK. The device uses a moving strip of organic photochromic reversible film in a transport similar to that for magnetic tape. Storage is accomplished by formation of 4 or 5 overlapped (reference angle multiplexed) holograms on the tape by illumination of a page composer and the tape (reference beam) with laser light in the active band of the photochromic. Readout is done by reillumination of the hologram at the nonabsorptive wavelength, and imaging on a photodetector array. Effectively, the holograms can be read from 10^4 to 10^6 times before refreshing of the hologram is required. Long term fatigue of the tape is under study. The multiple holograms are written and read by multiple sets of equipment on the same tape. Overlapped or multiplexed holograms are used to lower illumination and mechanical requirements. The primary utilization of the resulting memory will apparently be in the category of a "super" magnetic tape peripheral with extremely high packing density.

In the final talk of the colloquium C.K. Marshall discussed the development in his company (Marconi Avionics Ltd., UK) of a holographically formed optical element for use as the beam splitter of a "heads-up" display on an aircraft. The principal disadvantage of current glass beam splitters is the loss of a large portion of the incident radiation. Holographically created gratings, on the other hand, can be tuned to represent a mirror over only a very narrow spectral region (the green output of the cathode-ray tube) and therefore can be much more efficient.

Although discussed only for this special application and mentioned only briefly in Croucher's presentation, it is probably this idea of using holography to synthesize optical elements that will find the greatest applications in optical systems. (Irving Kaufman and R.D. Matulka)

A QUANTUM OPTICS LABORATORY IN FRANCE

The Laboratoire d'Optique Quantique at Palaiseau France, near Paris, is a laboratory of the Centre National de la Recherche Scientifique (CNRS) and in addition has been associated with the Ecole Polytechnique for the past three years. The Laboratory, under the direction of Professor Jaques Ducuing, has a scientific research staff of about 17 personnel, 3 or 4 research students, and about 3 visiting scientists. A central theme of the work is nonlinear optics. Nonlinear techniques such as stimulated Raman scattering are used to produce tunable ir sources, and molecular energy transfer mechanisms induced by collisions in gases, liquids, and solids are being studied using single pulse stimulated Raman excitation or excitation by a two-beam Raman process of specific vibrational levels. Additionally nonlinear processes in integrated optics have recently been investigated.

The Laboratory has published several papers recently on the subject of the generation of tunable far-ir radiation using stimulated Raman scattering

(SRS) techniques. Drs. Robert Frey and Francois Pradere with Ducuing and other colleagues have been especially active in this area. One example of such work was the production of radiation from Q transitions in HCl tunable over the range 60-160 cm^{-1}. They used resonance enhancement to increase the efficiency of the process. Figure 1 shows the energy level diagram and photon energies used. A beam with

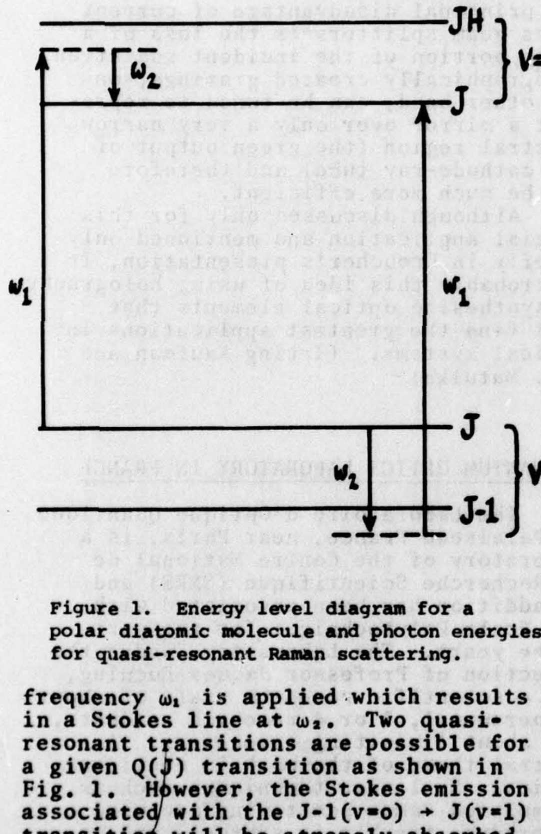


Figure 1. Energy level diagram for a polar diatomic molecule and photon energies for quasi-resonant Raman scattering.

frequency ω_1 is applied which results in a Stokes line at ω_2. Two quasi-resonant transitions are possible for a given Q(J) transition as shown in Fig. 1. However, the Stokes emission associated with the J-1(v=o) → J(v=1) transition will be strongly absorbed by the ground state J-1 → J transition, whereas the Stokes line associated with the J(v=o) → J+1(v=1) transition will not be absorbed, hence the Raman gain for the latter will be larger. This quasi-resonance scheme was first proposed by Ducuing, Frey and Pradere in 1976, and other workers have succeeded in doing the experiment.

Ducuing et al. applied the abovementioned technique first to HCl and later to HF. The pump beam was derived from a ruby laser pumped dye laser whose output was Raman shifted twice in gaseous hydrogen. The resultant pump source had the following characteristics: wavelength - 3.3 to 3.4 μm; energy - 40 mJ; pulse length - 2.5 nsec; and linewidth - approximately 0.1 cm^{-1}. The pump radiation is focused into a 50-cm long, 3-mm diam. light pipe within a cell containing pure HCl at a pressure of 40 Torr. They observed several tunable far ir-SRS lines for Q transitions in $H^{35}Cl$ (J=2 to J=7). In addition when the pump was near the R(J) line J → J+1, they observed laser action for J=5 and J=6 at the fixed frequency corresponding to the J → J-1 transition in the excited vibrational state as a result of Raman pumping of the upper state. The tuning was continuous over a small region, the size of which was pressure dependent, around each transition. At a pressure of 120 Torr the width was 2.34 cm^{-1}. The total spectral range obtained was 60 - 160 cm^{-1} (167 - 62.5 μm) with a photon efficiency of 12%.

These experiments were repeated in HF to obtain emission in the 50 - 250-μm range. Continuous tuning over the range 0.7 - 7.7 μm with a multi-megawatt output has been obtained using SRS in gaseous H_2 and extended to longer wavelengths (15 - 18 μm) by SRS in liquid N_2. Ducuing believes it is possible to generate tunable radiation at any wavelength less than 16 μm using these techniques.

Another area in which this Laboratory has made a new contribution is in energy transfer between molecules in gases, liquids, and solids in which a specific vibration-rotation level is populated by SRS or a two-photon method. They had performed earlier experiments on energy transfer in organic polyatomic liquids where decay times were in the picosecond range and relaxation processes were rather complicated. The tendency recently has been to study simpler diatomic molecules such as N_2, H_2, CO, and O_2. Relaxation times in these molecules are several orders of magnitude longer than for the organic molecules studied, and the relaxation processes are easier to understand.

Drs. G.M. Gale and C. Delalande have made some recent investigations in liquid H_2 including effects of isotopic impurities [*Chemical Physics* 34, 205-217 (1978)]. The experimental source consisted of a Q-switched ruby laser producing a 30-nsec pulse from which

a 2.5-nsec segment was chopped out with a Pockels cell. This pulse was amplified to a power level of 100 MW and focused into a cruciform liquid cell containing either pure H_2 only or H_2 with small amounts of HD or D_2. The v=1, J=1 level of orthohydrogen and J=0 level of parahydrogen were excited by SRS. However, this manner of exciting specific levels was somewhat inadequate as some transfer to higher vibrational levels owing to V-V transfer occurred. The solution to this problem is to reduce the number of excited molecules which is difficult with SRS. This problem was overcome by using ordinary absorption by excitation at 1.64 μm which excites two molecules per absorbed photon to the v=1 state. The 1.64-μm radiation is obtained by stimulated second Stokes scattering of the ruby laser pulse in a room-temperature H_2 gas cell.

The collision-induced fluorescent decays in the ir were observed for H_2*, HD*, and D_2* where the asterisk signifies excited state. The normal fluorescence in the the absence of collisions would be several seconds, but in the experiment, collisions shorten the relaxation times to the range 2 μsec-2 msec. Studies were made of V-V energy transfer in the liquid state between 15 and 30 K along with V-T transfer of excited impurities by liquid H_2. Measurements were also made in solid H_2 near the triple point.

The results of this investigation showed that there is no apparent discontinuity across a gas/liquid phase transition. The reciprocal of the relaxation time, τ^{-1}, remains a linear function of molecular density as the sample is changed from a low density gas to a liquid. A small nonlinearity did develop when the liquid was pressurized. They found that $\tau \propto (N^{-1/3}-\sigma)$ where $N^{-1/3}$ is the intermolecular distance and σ is an effective collision diameter.

Another very recent investigation has been started in Ducuing's laboratory in the area of bistable optical elements. Dr. Peter Smith from Bell Laboratories in the US is spending a sabbatical with the group. Smith has been working in this new field in the US hoping to apply it to integrated optics. Basically, these devices are transparent, have nonlinear properties as a function of optical intensity, and demonstrate hysteresis when cycled from low to high intensity and back again. Also, if a material demonstrating nonlinear behavior in its index of refraction as a function of intensity is placed in a Fabry-Perot cavity, the transmittance will depend critically on intensity as the optical thickness determines the resonance condition. In addition, if the material has an electro-optic coefficient, feedback can be obtained by applying a voltage proportional to the transmitted intensity to the material. Smith has teamed up with Dr. Jean-Paul Hermann (of Ducuing's group), who is developing some organic materials which have relatively high electro-optic coefficients. Combining these new materials with Smith's techniques should produce some very interesting results. It may be possible to produce a device which when used in conjunction with a photovoltaic detector will operate with no external electric power requirements. The goal of their work is to develop integrated optics devices such as harmonic frequency generators, modulators, switches, and logic elements.

This Laboratory, while concentrating on nonlinear optics, still maintains broad coverage in quantum optics through clever utilization of various nonlinear techniques. (Vern N. Smiley)

PSYCHOLOGICAL SCIENCES

AIRCRAFT ACCIDENT AND SAFETY RESEARCH IN NATO

The Advisory Group for Aerospace Research and Development (AGARD) is an effort to muster aeronautical engineering and allied sciences for NATO's aviation enterprises. For those who need reminding, AGARD was born in the disruption of scientific cooperation during WWII. When NATO appeared in 1949, Dr. Theodore von Kármán, the great aeronautical scientist, saw it as a vehicle for renewing international scientific cooperation by mobilizing scientists for NATO. AGARD was the outcome, and its first general assembly was held in 1952. AGARD is organized as 9 technical panels whose 400 members are experts from academic institutions, government laboratories, and industry. Panels hold two meetings a year, with a different country as host each time.

One of the panels is the Aerospace Medical Panel on the physiological and psychological aspects of flight, and its 35th meeting was held in Paris on 6-10 November 1978. One hundred sixty panel members and observers from 13 countries came to hear papers in a two-part program. One part was entitled "Models and Analogues for the Evaluation of Human Biodynamic Response Performance and Protection," and the other was entitled "Human Factors Aspects of Aircraft Accidents and Incidents." The first part of the program was organized by H. von Gierke (Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH), and it was dominated by MDs and physiologists. The second part, organized by B. Hartman (USAF School of Aerospace Medicine, Brooks AFB, TX), had more psychologists than any other specialty.

The first part of the program on models and analogues dealt with the response of the human body to disturbing physical influences, both of the violent kind and the more tolerable but debilitating kind like g forces or vibration. The presentations tilted in their emphasis toward effects of violent impact on the human body. Some of the research was empirical, such as the French work reported by B. Vettes and R. Eckert (Centre d'Essais en Vol, Bretigny-Air, France) that studied the effects of a controlled helicopter crash on instrumented anthropometric dummies. The most notable research that was reported, however, was on mathematical models of the human body in violent situations. Exploring a model with a computer is far cheaper than empirical studies of violence.

Models can represent the whole body and can include aspects of harness restraint systems and cockpit geometry, or they can be for key parts of the body like the spine and the head which are particularly vulnerable in crashes. As an example of a whole-body model, I. Kaleps (Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH) reported on the Articulated Total Body Model that had the human body divided into 15 parts, with the model representing the physical properties of the parts and the 14 joints connecting them. The model also included a representation of restraining systems and the influences of forces upon them. The most ambitious whole-body model was reported by G. Frisch (Naval Aerospace Medical Research Laboratory, Michoud Station, New Orleans, LA) that included not only the whole body of the simulated pilot but cockpit geometry as well. The output of the model is real-time animation rather than charts and graphs. A use of the model could be to specify an ideal cockpit design that would minimize injury to the pilot under various crash conditions.

Other models were less ambitious but no less important. A. King, S. Nakhla, and N. Mital (Bioengineering Center, Wayne State University, Detroit, MI) used a model of only the head and the spinal column for a parametric study of the neck response with and without a helmet. The helmet is a principal variable for the neck response because it increases the mass and mass moment of inertia of the head. The helmet is held to be an item of unquestionable importance for safety, and undoubtedly has its virtues, but these investigators established conditions in which the helmet increased the severity of the neck injury.

The second part of the program on aircraft accidents was a heartening story of progress, if accidents can be described as heartening. A. Zeller (Directorate of Aerospace Safety, Air Force Inspection and Safety Center, Norton Air Force Base, CA) reported on three decades of USAF efforts to reduce accidents, and it is an impressive record. The number of major aircraft accidents dropped from a rate of 64 per 100,000 hours of flying in 1947 to a rate of 2.8 in 1977. The rate of aircraft destroyed has dropped from 15 in 1947 to 2.4 in 1977. The rate of fatal accidents dropped from 6 in 1947 to 1 in 1977. The functions for these 3 measures have been near their asymptotes for the past 5-10 years, which says that there is little hope for further improvement. Whatever the USAF has been doing to minimize accidents, they have been doing it well, and it is hard to see what systematic remedial factors they could pursue to lower their accident rate even further with it as low as it now is. It seems fair to contend the same for the commercial airlines; their impressive safety record is known to us all. If this is so, analysts are left with an examination of fortuitous, rare case histories that have random causes and about which little can be done. Other presentations confirmed this thesis.

R. Taylor (RAF Institute of Aviation Medicine, Farnborough, Hants, UK) featured two near accidents based on the pilot's geographical disorientation, but these appear to be isolated cases. O. Weber (Institute for Flight Mechanics, DFVLR, Braunschweig, FRG) analyzed five midair collisions. He pointed out that midair collisions have been low in German airspace in recent years and that there have not been enough of them to determine causes and trends. D. Reader (RAF Institute of Aviation Medicine, Farnborough, Hants, UK) discussed pilot incapacitation in flight and said that it is a rare event. The probability of incapacitation is one occurrence in 8×10^5 flight sectors, with the probability of accident after incapacitation being 0.074. He suggested restraining methods to prevent the stricken pilot from falling on the controls, ranging from several kinds of harnesses to airbags, but the rarity of the event makes the cure worse than the disease. None of the data presented points to major accident variables that deserve prompt attention by the military air forces and commercial airlines of the world. (Jack A. Adams)

SPACE SCIENCES

AN OVERVIEW OF SPACE ACTIVITIES IN NORWAY

Unlike its Scandinavian neighbors Sweden and Denmark, Norway is not a member of the European Space Agency (ESA), but it does enjoy observer status through which it can participate in selected ESA programs on an *ad hoc* basis. Its national and international space programs are coordinated through the Royal Norwegian Council for Scientific and Industrial Research (NTNF), a branch of the Department of Industry. The Council is advised by the Norwegian Space Activity Committee which has three subcommittees: Committee for Space Research; Committee for Space Applications; and Committee for Remote Sensing. Management and execution of the space program as well as operation of the Andoya Rocket Range and the Tromso Telemetry Station are the responsibilities of the Space Activity Division (NTNFR). This organization is similar to that of the Swedish Board for Space Activities (*ESN* 33-2:72).

Norway has chosen to keep its space research program decentralized, and the NTNFR acts as coordinator of the numerous activities underway at various universities and research institutes. The primary institutions dealing with space experiments are the Department of Physics, Univ. of Bergen; the Institute of Physics, Univ. of Oslo; and the Norwegian Defense Research Establishment (NDRE). The Auroral Observatory at the Univ. of Tromso is concerned mainly with groundbased activities. The Christian Michelsens Institutt, Bergen (CMI), works closely with the research institutes mentioned above in the construction, integration, and test of satellite, rocket, and balloon experiments. This Institute also carries out limited space research programs particularly in the applications area.

Space research programs in Norway center upon studies of the ionosphere and magnetosphere and of auroral phenomenon. The high latitude of the rocket launch facility near Tromso lends itself well to the enhancement of these endeavors. Typical studies at the Univ. of Oslo include optical analysis of auroral emissions, measurements of the generation and propagation of naturally occurring electromagnetic emissions in the 10 Hz-1 MHz range, electric field diagnostics in the upper atmosphere, and measurement of ionospheric irregularities. Groundbased coordinated measurements of elf/vlf emissions, micropulsations, and auroral luminosity will play a major role in future programs.

The Univ. of Bergen works closely with the Univ. of Oslo and other Swedish research institutes in studying the ionosphere and magnetosphere through joint rocket, balloon, and satellite programs. One of the programs involves the investigation of the upper atmosphere hydrogen Doppler profile using rocket data on both auroral light and charged particles. Another program underway at Bergen is the study of plasma instabilities and irregularities in the auroral E-region using a combination of ground-based radar and *in situ* measurements. Detailed measurements of electric field, wave spectra, and plasma properties made from a rocket combined with radar data will give a new basis for studying the fundamental physical problems concerning E-region waves and irregularities. The rocket will be launched from the Andoya range at a time determined by the presence of radar auroral echoes in the region of the rocket trajectory.

NDRE is a civilian organization directly responsible to the Ministry of Defense. It is a highly sophisticated research establishment with a scientific staff of over 180 persons that has provided several members of the NTNFR and its subcommittees. NDRE has been active in radio geophysics since its inception in 1946. Special emphasis is now being placed on studies of processes that govern the polar ionosphere. Radio communications during auroral conditions are of particular interest both to the defense and commercial communications communities. Most of the research is carried out using sounding rockets and balloons in cooperative programs with foreign groups. NDRE will have an experiment on Spacelab to study the physical processes behind the formation of auroras. This will involve the development of an electron accelerator and various plasma diagnostic instruments in cooperation with ESA and several research groups in France.

On the applications side of space research, NTNF is supporting several programs in the field of maritime satellite communications. A large portion of NTNF's application budget is being devoted to the international MAROTS maritime satellite communications system. The space segment participation is *vis à vis* a subcontractor role to British Aerospace Dynamics in the communications subsystem package. On a national level, ship terminals are being developed under contract with United Marine Electronics on a 50/50 cost sharing basis. Also, at the national level, buoy electronics and test equipment for data collection and localization via satellite are being developed at CMI. In addition to the maritime ventures, studies of the use of satellites in situations of distress, search and rescue, navigation, and television broadcast have been underway for several years.

The area of remote sensing has had its ups and downs in Norway primarily because of the lack of customers for data. Earlier this year a new Committee for Remote Sensing was set up to determine the direction of such programs in Norway. The telemetry station at Tromsø receives data directly from TIROS N, NIMBUS G, and Applications Explorer Mission (AEM) and until its early demise also from SEASAT A. The station is capable of operating three separate antenna systems, the prime antenna being a 30-ft autotracking L- and S- band system. The station can distribute quick-look images to various users with appropriate data analysis facilities, and is expected to have facilities for data storage in 1979.

The highly sophisticated electronics industry in Norway has been heavily incorporated into its space program, and in the area of satellite technology, computer systems have been developed for antenna beam steering, satellite tracking, and digital communication systems. The cryptographic equipment for the US/USSR "Hot Line" was developed and built in Norway, and spread spectrum and PACKET switching equipment are under development for commercial and military satellite communication systems. Further, many of the sophisticated particle, electric, and magnetic field detectors flown on Norwegian and other national rocket and balloon experiments are designed and built by Norwegian research institutes.

The general interaction between universities and research institutes engaged in space science and technology in Norway is excellent and a great deal of cooperation is evident. This is, of course, partly because of necessity owing to limited funds, but it also results from genuine mutual professional respect between Norwegian scientists, engineers, and administrators. (Robert W. Rostron)

SYSTEMS SCIENCES

THEY'VE TAKEN THE FUN OUT OF IT

As everyone knows, Operations Research (or, as they call it, Operational Research) was invented by the British about 1940 and successfully applied to military problems by both the UK and the US during WWII. The first civilian application of OR was also in the UK, namely in the British Iron and Steel Research Association (BISRA), where an OR group was set up in 1945. Like most things that everybody knows, the true situation is a good deal more complicated, but the above is basically true; so I decided to visit BISRA to find out how OR had made out in the intervening years. This turned out to be impossible, because the steel industry has been nationalized and BISRA itself is being dismantled (and will be com-

pletely closed before this article appears in print). But its successor, the OR group in the British Steel Corporation, is in some sense the oldest civilian OR group in the world; so I went to see K.D. Tocher, who has been head of this group since the memory of man runneth not to the contrary. Tocher is one of the great men of British OR, with his roots in its very origins, and is highly respected in both the theoretical and applied aspects of OR—he is one of only two men on the British OR scene who has been awarded the Doctor of Science degree, which is very prestigious in the UK.

In addition to the very early OR work at BISRA, the various steel companies (which later became British Steel) had adopted OR by 1950 or shortly thereafter. Many of these OR groups survived the nationalization; but a few years ago, when the cost-cutting started, they were consolidated. There are now three corporate groups (for England, Scotland, and Wales) and seven works-based ones, all groups smaller than ten people having been abolished. Tocher himself sits in Birmingham, in more or less solitary splendor, away from any of the individual groups. It follows that he spends a lot of time traveling.

Most of what Tocher told me about OR in British Steel was colored by the peculiarities of the Corporation. This is like any other corporation except that it has only a single stockholder who happens to be the British government. Steel was actually nationalized, denationalized, and renationalized; but there is no possibility of reversing this again. It would be too traumatic, and anyway there is no longer enough private capital in Britain to consider private ownership of such an enormous organization. There is, of course, some complaining about the nationalization: "The government doesn't let the chairman and the board get on with doing the job—they are always setting higher priorities on essentially political questions like the state of unemployment in the nation," but this is nonsense; an organization as large as British Steel cannot ignore such questions anyhow, and may indeed have to keep people employed in spite of a temporary lack of demand for their services. The difficulties come not from nationalization itself but from inappropriate measures of effectiveness guiding the directors of the firm.

A few years ago British Steel had a capacity of about 20 million tons per year, and were incapable of meeting the demand. The question in the late 1960s had been whether the target for expansion should be 28 or 36 million tons. Fortunately, the decision was made to go for 28. Subsequently, there has been a long-term and apparently irreversible worldwide decline in the demand for steel. At the present time British steel has a capacity of about 22 million tons, and demand of about 17 million tons. There are many reasons for this decline in demand, including new factories in third-world countries, lighter auzomobiles, and less steel used in the construction of modern buildings. Whatever the reasons, British Steel is showing major financial losses year after year, and this has dominated the thinking of its directors. The exact magnitude of this loss is subject to some interpretation: officially it is £350 million per year, but in fact almost all of this is in interest (which is a sunk cost), and the actual operating loss is comparatively small.

During the 1970s many plants have been closed, and others enlarged or new ones constructed, in order to achieve both the economies of technologically advanced equipment and economies of scale. All of this has been terribly expensive, not only in capital equipment expenditures, but also in labor costs. The closing of old plants required that large sums be paid for "redundancies" (British jargon for those laid off)—on average more than a year's salary! There is a bright side to the picture: they have eliminated all of their obsolete equipment (such as open-hearth furnaces) and, like Germany and Japan, but unlike the US, can operate efficiently with existing equipment. But they do have this debt load. Furthermore, economies of scale cause other problems. It is true that a big blast furnace costs less than several little ones. But a blast furnace must be run continuously, and so you must use all that iron, and so it must be surrounded by lots of steel-making capacity. Furthermore, the blast furnace must be shut down for repair every few months, so you must have a spare to keep the steel capacity busy; and since the shutdown is only a small fraction of the operating time, you really should have several operating blast furnaces as against one spare.

Another key problem has been finding adequate managers for these large plants. The average tenure of a works-based divisional managing director has been three years—this is increasing now only because they have discovered that if you fire one, you're not going to get a better one. The problem is that while the nationalized firm can pay competitive salaries, nobody in Britain is interested in salaries because of the confiscatory taxes at the higher salary levels—and British Steel cannot arrange the "perks" (tax-free perquisites) by which private firms can attract the best managers.

And over all are the labor issues. It is essentially impossible to fire anyone, but every department has a significant fraction who are hoping to be fired so they can get redundancy pay. In any case, tensions between labor and management are much higher in the UK than in the US.

The bottom line of this lengthy introduction is that the policy is to cut costs, in some cases blindly and with highly adverse consequences. For example, BISRA was closed because its work was "too theoretical," "not useful," and so on. But all of the central expertise on process control was there, and it was not possible to retain these key people. It thus seems possible that the losses from inefficient process control will greatly exceed the savings from closing this research organization.

The OR group does not seem to be faced with this particular threat. Their total annual budget for a staff of about 150 people is about one million pounds (salaries are a good deal lower in the UK than the US), and their last benefit count showed savings of 29 million directly attributable to their efforts. Typical of the kind of thing which they have been doing and which has tremendous pay-off are the following recent studies:

How does one mix the various forms of scrap iron in preparing various forms of steel? In particular, stainless steel typically has 18% nickel and 8% chromium; it is desirable to utilize scrap which has a lot of nickel and chromium to make such alloys, but it is not possible then to remove other metals that may be in the scrap, and the final alloy must, for example, have less than 0.01% of lead. Furthermore, all of the available scrap has to be used somewhere; if put into the blast furnace, it is easier to remove some of the undesirable impurities, especially sulfur. This is a straightforward linear programming (LP) problem, but like most such problems, it is somewhat complicated in the implementation. Nonetheless, it is now operating and saving large sums of money.

Another similar problem concerns the allocation of iron-bearing materials to various furnaces. The iron-bearing materials include 20 to 30 categories of ore, and reduced iron which can be either made or purchased. The furnaces are of different types (arc, BOS). The orders must be distributed among mills, and this tends to be an LP problem, but some of the mills have to be shut down, which leads to integer variables. These problems turn out to be very large, and decomposition doesn't work, so most of the time is spent trying to reduce the size of the problem—it isn't that the computer won't handle hundreds of constraints and thousands of variables, it's just that such a big matrix requires years to collect the necessary data. But when it comes to shutting down a particular mill, the local union gets very unhappy. When shown that they are not as productive at a certain class of products as some other mill, they insist that the model is not realistic because it doesn't take account of some subclass at which they are very good. This requires a finer product grouping—and the more finely the products are grouped, the smaller the forecasted consumption in each group and the less reliable the forecasts are, until the entire model output becomes unbelievable. Furthermore, there is a tendency to use such models as window dressing: when the model doesn't close the mill that the politicians want closed, one can change the order book until it works out in the desired way. This can turn off any OR team.

There has been a lot of success with the above types of models, however. And even more important are the planning models based on simulations. Tocher feels that one of the few ways you can increase the productivity of an OR man is to give him better tools—namely, better simulations and simulation languages. Furthermore, he feels that an OR worker is a craftsman and should actually work—including doing his own programming. He has about

eight people generating new software, mostly development of GSP into a new and improved language which, in association with the simulation group at Lancaster University, will soon be commercially available. Everybody does simulations, and they are used for a wide variety of research projects: What delays will be caused by a lack of crane capacity at a typical plant? How should various groups optimize their capital budgeting? In fact, the rules of the corporation state that no capital development will be given sanction until it has been simulated—but there are lots of exceptions, and the rule is only obeyed about two thirds of the time. Most of these simulations are of a particular plant or part of a plant. There are also simulations of the firm as whole, but these tend to be called "planning models" rather than simulations. Such models are very useful to those who are trying to stop expenditures in order to hold down costs—Tocher is convinced that some of these "logistics studies" have been used primarily to stall an expenditure.

So OR goes on at British Steel as it has for many decades, with the most obvious difference being the increased use of computers, especially in simulation. I quoted to Tocher the maxim that in any organization doing the same thing for thirty years, it would probably be best to fire everybody and start all over again. He agreed, but said "I can't fire them." I suggested that I was including him, and he agreed again, but pointed out that they couldn't fire him either. But then he turned morbid. Because of some complex rules involving indexing to avoid the effects of inflation, the ultimate value of his pension will increase more rapidly if he retires than if he continues to work; so he will have to quit just on a financial basis. Furthermore, the entire OR staff is unionized now. Come quitting time, they have to leave, or get paid time and a half. And even that may not be authorized if it hasn't been planned and cleared with the union ahead of time. It's hard to reward merit and virtually impossible to penalize the lack of it. And with memories of the good old days when a team of bright and dedicated guys might work through the night if they got sufficiently excited about a problem, Tocher averred "They've taken the fun out of it." So OR will doubtless continue at British Steel, as it has been there for all these years, but it is unlikely to provide many exciting developments. (Robert E. Machol)

NEWS & NOTES

INSTITUTE OF ACOUSTICS PROCEEDINGS

Since its founding in 1974 there has been considerable discussion within the UK's Institute of Acoustics of the issue of a Proceedings. For some time an effort was made to issue to members loose copies of short versions of papers presented at all meetings, and occasionally these have appeared in a bound copy, depending on the diligence and energy of the organizing group. At other meetings abstracts of papers have been issued, while at some specialized meetings the organizers have succeeded in issuing formal proceedings covering most or all of the papers presented.

Earlier this year the Institute succeeded in issuing its first Proceedings volume which covers its Medal Lectures for the period 1974-77. The intent in the future is to issue to the membership such a volume annually embracing lectures associated with the award of its Rayleigh, Tyndall (biennial), and A.B. Wood medals together with the Institute's Presidential Address (alternate years).

The first volume contains among other items the 1975 Rayleigh Lecture given by P.H. Parkin entitled "Acoustical Reminiscences"; The 1975 Tyndall Lecture delivered by M.E. Delany, which is an important historical review of Sound Propagation in the Atmosphere (see *ESN* 30-11:502); and the lecture delivered by P.A. Crowther on the award of the A.B. Wood Medal in 1977 entitled "Underwater Acoustic Boundary Scattering" (see *ESN* 31-6:254). The last is important as providing coverage of an extensive program of work conducted by Crowther which has received little previous publicity. (A.W. Pryce)

NEW *SCIENTIFIC RESEARCH IN BRITISH UNIVERSITIES, ETC.*

In "News and Notes" of *ESN* 30-6, June 1976, we announced that Britain's

well-known scientific register *Scientific Research in British Universities and Colleges* ceased publication with the then current issue 1974-75, and that a study was underway to determine how to publish such a register that would be self-supporting.

In response to many requests from academic and government bodies the British Library is now producing a new publication entitled *Research in British Universities, Polytechnics and Colleges* (RBUPC). RBUPC will appear annually in three volumes. The current prices (according to an advertisement from the BL) are:

Vol. 1 Physical Sciences £15 ($30) ea.
Vol. 2 Biological Sciences £10 ($20) ea.
Vol. 3 Social Sciences £10 ($20) ea.
(plus $2 per dollar check for conversion)

Orders for single or multiple volumes should be sent to:

RBUPC
British Library
Boston Spa
Wetherby
W. Yorks, LS23 7BQ
England

PERSONAL

Dr. R.W. Nesbitt, Reader in Geology, Adelaide Univ., Australia, has been appointed to the Chair of Geology at Southampton Univ. from September 1979.

Dr. C.I. Pogson, Lecturer in Biochemistry, Univ. of Kent, has been appointed to a Chair of Biochemistry at the Univ. of Manchester.

Mr. E.G. Rees, Lecturer in Pure Mathematics at the Univ. of Oxford, has been appointed to the Chair of Mathematics at the Univ. of Edinburgh.

OBITUARY

Dr. Dennis Gabor, CBE, FRS, Nobel laureate, died 9 February at the age of 78. Born in Hungary, he spent his early career in Berlin, first as a student then as an engineer with Siemens and Halske. In 1933, he emigrated to Britain, where for 15 years he worked in the research laboratories of the British Thomson-Houston Company in Derby. It was during this time that the idea of holography, a system of three-dimensional photography, first occurred to him, as a by-product of his work on electron microscopy. Although originally conceived for use with election "matter" waves, he demonstrated that the application of holographic principles to the domain of light waves would yield true three-dimensional images. In 1949, Gabor joined the staff of Imperial College of Science and Technology as a Reader in Electronics, and was Professor of Applied Electronics from 1958 to 1967, when he retired. He then joined the CBS Laboratories in Connecticut as Staff Scientist. Twenty-three years after he had invented holography and the development of the laser had greatly simplified holographic techniques and extended the range of holographic application, his work had become fully recognized and Dennis Gabor received the Nobel Prize for Physics (1971).

ONRL REPORTS

C-13-78

THE SEVENTEENTH (INTERNATIONAL) SYMPOSIUM ON COMBUSTION by S.N.B. Murthy, I. Glassman, and J.R. Patton

The Seventeenth International Symposium on Combustion convened 20-25 August 1978 at the University of Leeds, UK. Sponsored by the Combustion Institute, the Symposium contained three colloquia on coal combustion, turbulent-combustion interaction, and fire and explosion. Papers discussed in this report are in the areas in which advances appear to be stimulating and technologically useful, such as soot, turbulent-combustion interactions, fire and explosion, coal combustion, propellants and explosives, deflagration to detonation transition, kinetics, and new measurement techniques.

R-7-78

SYSTEM DESIGN AND SOFTWARE ENGINEERING METHODOLOGIES IN EUROPE by D.C. Rummler, P.A. Santoni, H.G. Steubing, and R.J. Pariseau
(Distribution limited to U.S. Government agencies)

This report is the result of a survey conducted during 1978 of systems design and software engineering methodologies at various academic institutions, industrial facilities and governmental research establishments in the United Kingdom, France, and Germany. Specific activities surveyed include computer-based system requirements derivation system, design specification and program implementation methodologies, concepts and tools.